#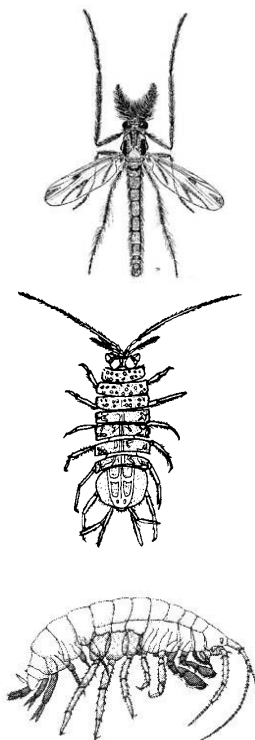 FINAL REPORT (2002-2004): Benthic Macroinvertebrate Communities of Reconstructed Freshwater Tidal Wetlands in the Anacostia River, Washington, D.C.

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ABSTRACT

Considerable work has been conducted on the benthic communities of inland aquatic systems, but there remains a paucity of effort on freshwater tidal wetlands. This study characterized the benthic macroinvertebrate communities of recently reconstructed urban freshwater tidal wetlands along the Anacostia River in Washington, D.C. The focus of the study was on the two main areas of Kingman Marsh, which were reconstructed by the U.S. Army Corps of Engineers in 2000 using Anacostia dredge material. Populations from this 'new' marsh were compared to those of similarly reconstructed Kenilworth Marsh (1993) just one half mile upstream, the relic reference Dueling Creek Marsh in the upper Anacostia estuary and the outside reference Patuxent freshwater tidal marsh in an adjacent watershed. Benthic macroinvertebrate organisms were collected using selected techniques for evaluation including the Ekman bottom grab sampler, sediment corer, D-net and Hester-Dendy sampler. Samples were collected at least seasonally from tidal channels, tidal mudflats, three vegetation/sediment zones (low, middle and high marsh), and pools over a 3-year period (late 2001-2004). The macroinvertebrate communities present at the marsh sites proved to be good indicators of disturbance and stress (Kingman Marsh), pollution, urban vs. rural location (Kenilworth and Patuxent), and similarities between reconstructed and remnant wetlands (Kenilworth and Dueling Creek). Macroinvertebrate density was significantly greater at Kingman Marsh than Kenilworth Marsh due to more numerous chironomids and oligochaetes. This may reflect an increase in unvegetated sediments at Kingman (even at elevations above natural mudflat) due to grazing pressure from over-abundant resident Canada geese. Unvegetated sediments yielded greater macroinvertebrate abundance but lower richness than vegetated marsh sites. Data collected from this study provides information on the extent that benthic macroinvertebrate communities can serve as indicators of the relative success of freshwater tidal marsh reconstruction.

BACKGROUND and JUSTIFICATION

The U.S. Army Corps of Engineers (CoE) has been the lead agency in conjunction with the District of Columbia Department of Health (D.C.) and the National Park Service (NPS) in the effort to reconstruct and restore several freshwater tidal wetlands along the Anacostia River in Washington, D.C. on NPS managed lands. This large-scale effort justified a rigorous post-reconstruction monitoring program to evaluate the level of success in recreating the wetlands and their multiple habitats. The areas in question had once been vital freshwater tidal wetlands but had been removed through mandatory dredging by the CoE during the first half of the 20th century. Recently, the CoE has used various program components to justify rebuilding some of the lost wetlands using dredge material available from the heavily sedimented Anacostia River channels.

Historically, the Anacostia estuary was a fully functional freshwater tidal marsh comprising several thousand acres that provided considerable food and habitat for wildlife and thus was an invaluable support resource for the local Indians and subsequent colonists. Towards the end of the nineteenth century as sewage pollution, agriculturally derived sediments filling the shipping channel, surrounding development, and disease threats increased in the Anacostia , intense pressure developed to remove what were perceived as problematic wetlands. The CoE was given the charge to dredge the Anacostia from its mouth at the Potomac River in Washington, D.C. up to Bladensburg, Maryland. In addition to dredging, a stone seawall was constructed which formed a hard boundary between the dredged river channel and the deposited fill behind the seawall. Essentially no emergent wetlands remained (except for narrow edges of transitional wetlands) including areas within the dredged out tidal Kenilworth and Kingman Lakes. The NPS eventually became the custodian of these newly built landscapes which were to be used mostly for recreation. In the 1980s park planners and resource managers began to envision the opportunity of restoring areas like Kenilworth Lake to marshlands as a vestige of the once productive wetland habitat. Following a long series of planning and technical evaluations, Kenilworth Marsh was reconstructed in 1993 by the CoE for the NPS as a freshwater tidal marsh (32 acres/13 hectares) in the highly urbanized Anacostia watershed (Bowers 1995, Syphax and Hammerschlag 1995).

Currently the Anacostia watershed, which drains portions of Montgomery and Prince Georges Counties in Maryland as well as the eastern portion of Washington, D.C, is about one-half urban, one-third forested and the remainder primarily agriculture. The presence of sand and gravel strip mines coupled with the considerable urbanization in the watershed resulted in excessive stormwater flows containing elevated levels of sediment. It is these sediments (the heavier sediments dropped out first in the upper portions of the estuary) which were used to rebuild the wetlands. In the past, and to a lesser extent currently, the Anacostia carried high levels of contaminants. Sediment contaminant levels are high enough in organic pollutants such as PCBs, chlordane and PAHs for there to be strict limits of fish take from the river. In fact, the Anacostia has been labeled as one of the three most contaminated water bodies in the Chesapeake Bay. One function of rebuilt wetlands is to help mitigate impacts from the runoff. The entire tidal Anacostia from Bladensburg to the Potomac contains only fresh water. The salt wedge from the ocean and bay does not make it up to Washington, D.C. The reference Patuxent

watershed is more rural and contains two dams along the mainstem with smaller impoundments elsewhere that together limit runoff impacts from portions of the developed landscapes.

In 2000, portions of Kingman Lake along the Anacostia estuary about one quarter mile south of Kenilworth Marsh but on the right (west) bank (*Photograph 1*) in Washington, D.C. were reconstructed to emergent freshwater tidal wetlands (Kingman Marsh). The process involved using a hydraulic dredge to pump a slurry of somewhat contaminated Anacostia channel sediments (variable amounts of anthropogenically derived chemicals such as chlordane, PCBs and PAHs) by a CoE contractor into two separate containment cells at Kingman (Kingman Area 1 and Kingman Area 2). Following dewatering and consolidation the resultant sediment flats covered about 35 acres and were planted with 700,000 plants comprising 6 native species. Volunteer plants also began to grow from the soil seed bank but mostly from propagules transported in by water and air. Much of the planted areas were surrounded by corrals of light plastic fencing to exclude geese and ducks which grazed the new plantings. As a component of this reconstruction project the CoE in conjunction with D.C. established funding for 5 years of post- reconstruction monitoring (2000-2004) for two elements: (1) food chain accumulation of contaminants (conducted by the Fish Wildlife Service) and (2) vegetation establishment (conducted cooperatively by USGS Patuxent Wildlife Research Refuge and the University of Maryland Biological Resources Engineering Department) (Hammerschlag et al., 2006). Moreover, based on the expected usefulness of benthic macroinvertebrate data and the paucity of practical information in the literature covering such freshwater tidal organisms,, the CoE and D.C. decided to fund much of this special three year study (2002-2004).

The USGS Patuxent Wildlife Research Center (USGS PWRC) in conjunction with the University of Marylacnd Department of Biological Resources Engineering has been involved with the documenting the pre-and post-reconstruction status of urban freshwater tidal wetlands in the Anacostia River (Hammerschlag et al., 2006). The District of Columbia Department of Environmental Health, Baltimore District of the Corps of Engineers and the National Capital Region of the National Park Service sought the expertise residing at USGS PWRC to conduct a detailed benthic macroinvertebrate study covering the Anacostia and reference wetlands as one of the post-reconstruction wetland status indicators of wetland status. Kingman Marsh (reconstructed in 2000) was the study focal point, but collected data from all the study wetlands was used to support required monitoring and project baseline studies for the numerous reconstruction projects in the tidal Anacostia being implemented by CoE and D.C.

The high cost investment, high visibility and challenging circumstances for successful freshwater tidal wetland reconstruction in urbanized Washington, D.C. justified multi-year monitoring to measure the level of marsh reconstruction success. Benthic macroinvertebrates were used as short-term indicators given that most taxa of the macroinvertebrate community have relatively short life cycles (<2yrs.) and remain sedentary. It was possible to evaluate the extent the urban reconstructed wetlands were evolving toward reference wetlands, particularly in terms of habitat and pollution influences. Literature review revealed a paucity of information pertaining to the macroinvertebrate communities of freshwater tidal wetlands which justified examining multiple sampling methods and community types to document the efficacy of using the benthic macroinvertebrate community as an indicator system reflecting wetland status.

There were special challenges in pursuing this work including tidal cycles and fluxes determining varying inundation periods for the marsh zones. How would macroinvertebrate communities respond to differing periods of flooding? We attempted to characterize the macroinvertebrate communities in six selected tidal marsh zones (habitat areas) which we felt would be discrete, yet representative. A measure of adaptive sampling was involved. Characterization of these benthic communities, based on metrics such as abundance, taxonomic richness and pollution tolerance, provided a practical bioassessment. These determinations were compared to other indicators to further validate the usefulness of benthic organisms as short-term indicators of reconstructed wetland health. Such information will be important to assess progress of the reconstructed Anacostia wetlands and others like them. This study also utilized information from other studies involving the marshes in question concerning such parameters as vegetation, hydrology, sedimentation processes, soil structure and soil properties. While not directly addressed in this study, resident Canada goose herbivory severely impacted the vegetative cover at Kingman Marsh (Hammerschlag et al. 2006). It is not known how this may have influenced the macroinvertebrate community, although some differences between Kingman and the other Anacostia marshes may be related. Since the Anacostia is a tributary to the Chesapeake Bay, this study will be contributing to the base of information used to better understand the ecology of the Chesapeake Bay system.

OBJECTIVES AND TASKS

The study hypothesis is that the benthic macroinvertebrate community can provide a viable bioassessment of the reconstructed urban freshwater tidal habitat; or, more statistically stated as a null hypothesis - the benthic macroinvertebrate community will not suffice as an indicator of successful wetland reconstruction. While the overall objective of this study was to evaluate the relative success of urban freshwater tidal marsh reconstruction using the benthic community as an indicator, there are a number of task-oriented goals that were also pursued. Project tasks included:

- Identify macroinvertebrates to the most practical taxonomic level (usually family) that inhabit the urban Anacostia marshes (Kingman, Kenilworth and Dueling Creek) as compared to the more rural Patuxent Marsh.

- Determine whether time of marsh establishment (age) relates to differing macroinvertebrate communities by evaluating as a series: Kingman Marsh as reconstructed in 2000, Kenilworth Marsh as reconstructed seven years prior in 1993, Dueling Creek as an urban but last remaining relic marsh area in the Anacostia, and a relatively undisturbed Patuxent marsh area in an outside, but adjacent watershed.

- Compare the macroinvertebrate communities from the three urban Anacostia wetlands (Kingman, Kenilworth and Dueling Creek) to the more rural Patuxent Marsh.

- Evaluate the influence of marsh (sediment) elevations (elevation gradient effect) and tidal regimes on macroinvertebrate community composition in the freshwater tidal system by sampling channel; mud flats (exposed at low tide); low, middle and high marsh zones; and stable yet transient pools.

- Use combinations of quantifiable methods of sampling (multi-sampler technique) such as the Ekman dredge and corers coupled with more qualitative benthic sampling devices such as sweeps with D-nets and placement of Hester-Dendy samplers over periods of time.

- Compare the macroinvertebrate populations of the reconstructed marshes (Kingman and Kenilworth) with the non-reconstructed marsh areas of Dueling Creek and Patuxent.

- Evaluate the various wetland macroinvertebrate communities for pollution tolerance, especially by comparing to established lists.

- Compare the results from this study with those from similar wetland projects as may be reported in the literature.

- Conclude to what extent the benthic macroinvertebrate community can serve as one of the indicators of the status of freshwater tidal marsh reconstruction.

METHODS and TECHNIQUES

This three-year study was conducted during years 3-5 post-reconstruction at Kingman Marsh (2000) and years 10-12 post-reconstruction of Kenilworth Marsh (1993). It was designed to target and compare like habitat units (channel, mudflat, low marsh, middle marsh, high marsh and pools) in each of the four freshwater tidal wetlands differing in age or mode of establishment - **Patuxent Marsh** including Mill Creek channel (*Photograph 2*) = a relatively rural watershed (Anderson et al.1968) adjacent to the urban Anacostia watershed and used as a reference site; and the **Anacostia wetlands** (*Photograph 1*): **Dueling Creek Marsh** = the best remaining unreconstructed wetland in the urban Anacostia (personal observation) and used as the Anacostia reference marsh, **Kenilworth Marsh** = reconstructed in 1993 located just one half mile upstream from Kingman Marsh and a half mile downstream from Dueling Creek Marsh, and **Kingman Marsh** = reconstructed in 2000 using Anacostia dredge material similarly to Kenilworth Marsh. Both Kingman Marsh, the focal wetland of this study, and Kenilworth Marsh are located in low energy backwater portions of the Anacostia estuary. The selection of the Dueling Creek site was based on its being the last best remaining piece of freshwater tidal marsh in the Anacostia, and since it had been used as a reference site for other Anacostia wetland studies there was an existing data base for it. Dueling Creek Marsh is a narrow elevated bench along the tidal Dueling Creek Channel that used to be part of the primary Anacostia channel but was cut off when a straight line channel was dredged to Bladensburg. Similarly, the Patuxent Marsh (*Photograph 2*) had been used for other studies and thus possessed a decent data base. The Patuxent study site, the more rural non-Anacostia sampling location, straddles Route 4 which makes it accessible. Mill Creek is a small tidal channel that is part of the primary Patuxent Marsh study area.

Methods for sampling tidal wetland macroinvertebrates have not been as well documented as the protocols for monitoring streams (Adamus and Brandt 1990). Designing an effective sampling program for freshwater wetlands presents several challenges. First, choosing

appropriate sample sites is not straightforward. Marshes are usually patterned into a mosaic of discrete vegetation associations, and sampling will need to be stratified with respect to these large-scale patterns (Turner and Trexler 1997) so as to reflect habitat types and sediment elevation in the tidal regime. Marsh vegetation may also be very dense, and the sampler used in these habitats must be able to perform effectively. Finally, marsh water levels vary by tides, seasonally and spatially, and macroinvertebrate samplers must be able to function at various water depths. Some sampling methods may integrate influences from changing tidal regime better than others. Sampling was conducted as close to high tide as possible to permit the use of various samplers along the vegetation community gradient and habitat types.

Also compared with each other were the four quantifiable sampling methods: Ekman dredge, core sampler, D-net and Hester-Dendy plate sampler. This project used these in a multiple sampler approach. The primary sampler was an Ekman bottom grab sampler which could be used facilely at all six habitat units. The Ekman sampler measures 6"x 6"x 6" (216 cu. in.) and samples a 0.023 m^2 area of sediment. The sampler is attached to a 5' extension handle and has a spring loaded trap door to retain grabbed samples, which allows for shallow water operation. The Ekman was used as a quantitative means of sampling, which permitted the estimate of the numbers of organisms per square meter. This approach has been well documented in the literature (Elliott and Drake 1981, Lewis et al. 1982, Merritt and Cummins 1996, Brittingham 1997, Helgen 2001). At each sample site, three Ekman grabs (three replicates) were taken for statistical confidence. In the field, the sediment sample was washed in a 600 μ mesh sieve and the contents were placed in 70% alcohol stained with rose bengal to preserve for laboratory identification and enumeration.

The other types of samplers used included the dip net (D-net), Hester-Dendy plate sampler (HD), and a core sampler. The D-net has a 12-inch diameter opening with an 800 μ mesh. The D-net was used to take an approximate 1-meter sweep of the sample site water column with a horizontal bumping action along the bottom (thus the need to sample near high tide for several of the six habitat types). The D-net method represented a qualitative mean of sampling yielding a general assessment of the taxa of aquatic organisms present in the water column (these may be organisms brought in on the rising tide) and surface sediments, as well their relative abundance (Swanson 1995, Merritt and Cummins 1996, Helgen 2001). D-net samples were taken in series with the Ekman samples to capture other organisms present that the Ekman sampler may have missed by not including the water column. It was used to sample each of the vegetation zones (low, middle and high marsh) at each season. Samples were washed in the field and preserved in 70% alcohol with rose bengal.

The Hester-Dendy is an artificial substrate sampler placed in areas essentially remaining covered by water that attracts mobile macro-benthic organisms seeking protection such as aquatic insect larvae, amphipods, sphaerids, etc.. It is composed of nine 3-inch square plates separated by spacers held together by an eyebolt and wing nut. The H-D is a quantifiable means of sampling that enabled us to better determine the full spectrum of organisms present in the marsh habitat (Merritt and Cummins 1996). The sampler usually was tied to a stake which serves as a locator and placed below the surface of the water for a period of four to six weeks. At the end of this time the sampler was removed, disassembled, carefully washed and scraped clean. Material collected from the substrate was washed and placed in the 70% alcohol solution

for laboratory identification. H-D samplers proved difficult to maintain in the tidal regime, especially over winter. Also, it was not always possible to keep inundated in the channels during very low tides. Sometimes vandalism or storms were likely causes for loss of the tethered samplers. As a result, while the H-D's provided a good picture of the presence of a series of organisms not as readily captured by other means, it could not be used as a quantitative sampling device in this study.

The core sampler is a round 8-inch long tube with a 4-inch diameter opening. The corer took a sample from each site by pressing it 3-4 inches into the sediment. This quantitative mean of sampling gave us another method to estimate numbers of organisms per unit area (Turner and Trexler 1997, King and Richardson 2002). In effect it could be used instead of the Ekman dredge especially where smaller sampling volume would work. The sediment cores were washed in a bucket with a 600 μ mesh bottom, and the contents preserved in the 70% alcohol solution. Use of the core sampler was discontinued beyond Year 1, after as expected, it was determined that it yielded similar results to the Ekman dredge. The core sampler may be efficient in sediments where it can 'pull' the sample but would be troublesome in soft or 'loose' water logged situations where it would be necessary to get your hand or perhaps a disk under the sampler to try to retain the sample.

The wetlands of the Anacostia River that were sampled are as follows: Kingman Marsh Areas 1 and 2 (*Maps 1 and 2*), Kenilworth Marsh Mass Fills 1 and 2 (*Map3*), and Dueling Creek Marsh (*Map 4*); and an outside reference marsh located along the Patuxent River (*Map 4*). Thus there were six sampling locations. Within each marsh location six separate habitats units were sampled: tidal channel (tidal guts or channels that carried water into and out of the wetland); pool (large areas that were depressed enough to hold water almost continuously); mudflat (low elevation zones that were exposed sediments at low tide; they were lower than any of the vegetation zones); and intertidal vegetation zones (low, middle, and high marsh) although when preliminary data suggested no significant difference in macroinvertebrate populations among the three vegetation gradient zones, though still sampled separately, results were pooled as one vegetation zone. Typical low marsh areas at Kingman Marsh were populated with such key species as *Peltandra virginica, Nuphar lutea, Pontedaria cordata* and *Zizania aquatica*. Mid marsh often contained *Schoenoplectus tabernaemontani, S. fluviatilis, P. virginica, Sagittaria latifolia* and *Juncus effusus*. High marsh often possessed dominants such as *Typha* spp., *Phragmites australis, and Lythrum salicaria* along with several annuals. A complete listing of species, common names and habitat preference may be found in the Final Report covering the vegetation study (Hammerschlag et al. 2006). In addition to the vegetation zones, there were usually only one or two durable pools per site.

Elevations for the intertidal vegetated zones (high, middle and low marsh) were surveyed using existing benchmarks installed by the CoE according to the National Geodetic Vertical Datum of 1929 (NGVD '29 = the mean tide levels recorded in the 1929 time period. Measurements of the benchmarks and vegetated zone sites were taken using a laser level and surveyor's rod. Guidelines for determining the elevations and inundation periods of the vegetated zones were taken from a technical report by Offshore & Coastal Technologies, Inc. (1996) submitted to the CoE for the Kingman Lake wetlands. According to the report, low marsh sites were inundated about 36% of the time and occupy elevations of 1.5' to 1.7' NGVD

'29; mid marsh sites were inundated about 27% of the time and occupy elevations of 1.7' to 2.1' NGVD '29; and high marsh sites were inundated about 19% of the time and occupy elevations of 2.1' to 2.3' NGVD '29. Mudflats were unvegetated areas less than 1.5' NGVD '29 and inundated more than 40% of the time with short periods of exposure to the atmosphere. At Kingman Marsh there were also disturbed mudflats where vegetation would normally occur but were devoid due to wildlife grazing. These were not sampled as 'mudflats'. Reconstructed marsh sediments often contained intact or partially decomposed organic matter fragments, but the soils did not contain a developed organic matter layer.

The sampling schedule for the three year study is shown in Table 1. Sampling was to be conducted at each collection site (6 = 2 at Kingman, 2 at Kenilworth and 1 at both Dueling and Patuxent) seasonally (quarterly) at randomly selected points within each of the above-mentioned site habitat units using the four sampling techniques for three consecutive years. By referring to Table 1 we can see the specific schedule for each of the six sites: the H-Ds were sampled every other month at the channel and pool habitats (*12 samples/year*); the core samples were taken at each of the 3 vegetated marsh elevations or as replicates in July, August and September at all sites but Patuxent (*9 samples/year*); the Eckman was grabbed as three replicates the first month of each season at the channel (12 samples/year) and mudflat (12 samples/year), 2 replicate samples were taken seasonally at the pool (8 samples/year) and one sample was collected at the 3 vegetated habitat unit zones each season (12 samples/year) or at least 3 vegetated zone samples (replicates) were taken each season since it was determined that no difference existed among the three vegetated habitat zones in terms of macroinvertebrate community (*44 Ekman samples/year*); and finally the D-net was used at each habitat zone, except that the vegetated zones were sampled as one of the three elevation based habitat units the first month of each season to in effect yield 4 habitat units sampled (*16 samples/year*). Thus a total of 81 samples were collected at each of the 6 collection sites each year for a subtotal of 486 samples which were reduced by 9 (no core samples at Patuxent) to yield a TOTAL of 477 samples/year. While this was a large sampling size to handle, it constituted the smallest number acceptable to meet the study design.

Samples brought back to the lab were washed again through the 600μ mesh screen and placed in trays for sorting and enumeration under a dissecting scope. All samples were picked to completion, no sub-sampling was used (It often took at least one hour to sort a sample, with some samples containing over 500 organisms.). Organisms were identified to the lowest taxonomic group (primarily to family, but to genera or even species where possible), preserved in 70% alcohol and placed in vials for a reference collection. Macroinvertebrate indentifications were verified by Rob Hood of USGS, Water Resources Division, Denver, Colorado; and Tim Morris of Cove Point Lab, Solomons Island, Maryland.

The data was compared using measurements most commonly used by aquatic ecologists: invertebrate abundance, species richness, relative abundance, and taxonomic composition. The mean ($\pm$1 SE) number of invertebrates per meter squared ($\#/m^2$) or density throughout the sampling period was calculated. A measure of diversity was calculated which combined richness and enumerations in a summary statistic. Total number of taxa (usually genera) provided a richness component in calculating the value of diversity indices; the number of individuals per taxon provided an evenness component (Washington 1984). We used Shannon's Index of

Diversity, which is the most commonly used diversity index. To contrast taxa abundance, we analyzed statistically only those taxa that represented >1% of the total number of individuals (i.e. common taxa) collected throughout the study. We used two-way ANOVAs to compare the abundances of the common taxa between the marsh sites, habitats, seasons, and collection year. A Tukey's post-hoc test was used to detect where the significant differences occurred. All data were $log_{10}(x+1)$ transformed prior to analysis to equalize variances (Zar, 1996).

Pollution tolerance was addressed by relating the species found to lists of documented pollution tolerant and intolerant species. Tolerance values were taken from the Maryland Biological Stream Survey (MBSS) 2000-2004 Report (Boward et al. 2005). Comparison also was made between the species found in the polluted Anacostia estuary (particularly as related to toxic components – Pinkney et al. 2003) as compared to the nearby less polluted situation at Patuxent Marsh.

RESULTS

Over the course of the study some 110,000 macroinvertebrate organisms were collected representing 70+ taxa (*Table 2*). The taxa include 11 genera and orders comprised of 31 identified families. Dipterans (aquatic flies) were the most diverse order representing over 20 species. Of the D*ipteran* order, the family *Chironomida*e was the most abundant group at each marsh with densities reaching over 20,000/m^2. The segmented aquatic worms (O*ligochaetes*) were the second most abundant group in the study with densities reaching 16,000/m^2. A family level comparison of the six marshes with combined data from the entire study involving all the sampling methods is shown in *Table 3*. Over 95% of the organisms counted at Kingman were either chironomids or oligochaetes and the count was over 85% at Kenilworth. While about 23 families were represented at the Anacostia wetlands (Kingman, Kenilworth and Dueling), Patuxent had contributions from 30 families. Also striking as revealed in the Shannon Diversity Index, is how more evenly spread the counts are among the families at Patuxent, not just clustered in the aquatic fly larvae and segmented worms *(Table 3)*.

Since the Ekman sampling method was used at all sampling locations and was the most quantitative, much of the analysis is based on those data. There was no significant difference in the data from year- to-year; therefore counts and percent total numbers were combined for the entire study (2002-2004) for each marsh. This was a very important factor in the analyses for this study. The lack of significant trends or year-to-year differences allowed the data for most of the comparison analyses to be combined which reduced variation and permitted stronger statistical results. Data from Kingman Area 1 and 2 as well as Kenilworth MF 1 and 2 were found to have no significant difference for major parameters measured such as abundance and richness. Therefore the data within each marsh was combined and labeled simply as Kingman and Kenilworth. There was also no significant difference seasonally from year-to-year for these factors; however there were seasonal differences within years, for example there were significantly greater abundances (mean #/m^2) observed in summer and fall than winter or spring (p<0.05)(*Figure 1*).

Based on mean #/m^2 over the course of the study, Kingman had a significantly higher abundance of macroinvertebrate organisms (7,500) than the other three marsh sites (p<0.05)

(*Figure 2*). Kenilworth and Dueling were similar in abundance, but significantly higher than Patuxent (p<0.05). All three urban Anacostia sites had significantly greater abundance than the more rural Patuxent Marsh (p<0.05). Thus the references sites, urban Anacostia Dueling Creek and rural Patuxent, were also significantly different from each other. However, the sites with the higher abundances also had the lowest taxa richness (*Figure 3*). The more rural Patuxent had significantly higher taxa richness than all sites, and Kenilworth was greater than Kingman and Dueling Creek which were similar with the lowest taxa richness (p<0.05). Using Shannon's Index of Diversity, we determined that Patuxent Marsh had a greater diversity and evenness than the other sites (*Figure 4*). Kingman had the lowest score, with Kenilworth and Dueling showing similar scores. This data derived from the Ekman sampler was similar to that displayed from all the sampling methods combined as can be derived from *Table 3*.

The top four taxa with respect to abundance represented in the data was calculated in *Figure 5*. The family *Chironomidae* and *Oligochaetes* made up the top two taxa at all four marshes. Another family from the dipterans, *Ceratopogonidae* and the family *Sphaeriidae* (fingernail clams) made up the other two. However, at Kingman, Kenilworth, and Dueling these four taxa made up the majority (99%, 96%, and 98%, respectively) of the total. At Patuxent these four taxa groups only made up 77% of the total. At Kingman and Kenilworth the preponderance of benthic organisms encountered were either *Chironomidae* or *Oligochaetes*.

When looking at only the *Chironomidae* data from the study, some of the same patterns emerged (*Figure 6*). Kingman had significantly greater chironomid density than the other three sites; Patuxent was significantly lower than the other marshes, while Kenilworth and Dueling were similar to each other yet differed from the other two wetlands (p<0.05). The O*ligochaete* data followed the same pattern as the family *Chironomidae*, with Kingman significantly greater and Patuxent less dense than the other marshes (*Figure 7*).

Kenilworth Marsh, which was reconstructed in 1993 and thus had a longer period than Kingman Marsh (reconstructed in 2000) to restore, was also less disturbed by geese than Kingman Marsh. Kenilworth in most of the macroinvertebrate comparisons was similar to the Anacostia reference site at Dueling Creek, but both Kenilworth and Dueling were different from Kingman. One case where Kenilworth was significantly different from Dueling was where it had a significantly greater taxa richness (p<0.05) (*Figure 3*). Thus the macroinveretebrate populations seemed to be a good indicator of wetland status with the disturbed urban Kingman Marsh differing from the more intact Anacostia marshes and the more rural Patuxent Marsh. That Kenilworth Marsh has many similarities to the reference Anacostia marsh at Dueling with respect to the macroinvertebrate community suggests the reconstructed Kenilworth wetland is now (10-12 years post reconstruction) becoming more like an unreconstructed Anacostia wetland.

A comparison of vegetated to un-vegetated sites was performed in order to get an idea of the effect that vegetation and/or elevation might have on macroinvertebrate populations. Did macroinvertebrate populations segregate according to vegetation cover and/or elevation in these freshwater tidal wetlands? Vegetated sites consisted of high, middle and low marsh, whereas un-vegetated sites were pool, mudflat and channel. Macroinvertebrate abundance was similar for Kingman between vegetated and un-vegetated sites; however again, both Kenilworth and

Dueling had similar comparisons to each other with un-vegetated sites supporting greater abundance than vegetated (*Figure 8a*). When looking at taxa richness (*Figure 8b*) vegetated sites had a higher richness than un-vegetated sites for all the Anacostia wetland locations but not Patuxent Marsh. A comparison of the habitat units established by marsh elevation (high, middle, and low marsh) to those below 1.5' NGVD '29 (pool, mudflat, and channel) for all marshes can be seen in *Figure 9*. Macroinvertebrate **a**bundance was significantly higher for mudflat and channel than for the other habitats with high, middle and low marsh similar to pool habitats (*Figure 9a*). Taxa richness was significantly higher for the vegetated zones (high, middle and low marsh) than for those sites below 1.5' NGVD '29 (*Figure 9b*).

There are similar findings when comparing data from the two main sampler types (Ekman and D-net). Mean Ekman and D-net numbers had the same pattern with Kingman having significantly higher individuals per meter squared than the other wetlands and Patuxent had less abundance (p<0.05) (*Figure 2* and *Figure 10*). Taxa richness for the two samplers also had a similar pattern with Patuxent having significantly higher richness than the Anacostia wetlands while Kenilworth had more taxa than either of the other Anacostia marshes (p<0.05)(*Figure 3* and *Figure 11*). This suggests that both samplers were obtaining a good representation of the macroinvertebrate communities in the sampled marshes. The Ekman did collect an order of magnitude greater number of organisms than the D-net.

Pollution tolerance values of the common macroinvertebrate taxa are shown in *Figure 12*. Tolerance values were taken from updated MBSS Technical Report of 2005 (Boward et al. 2005). Tolerance values were calculated for lowest taxon represented in each marsh (i.e., family or genera). Importantly, Kingman Marsh was significantly different from the other wetlands (p<0.05), and there were no significant differences between Kenilworth, Dueling Creek and Patuxent Marshes. Patuxent Marsh did have the lowest pollution tolerance score, but was not low enough to be significant. However, when compared on a watershed level, the macroinvertebrate tolerance levels of the Anacostia wetlands were significantly different from Patuxent (p<0.01) (*Figure 13*).

DISCUSSION

Overall, our data show that the macroinvertebrate populations reflect and indicate the character of the wetlands in which they are found. Taxa in the Anacostia reconstructed wetlands (Kingman, Kenilworth and the internal reference site Dueling Creek) had macroinvertebrate abundances significantly greater than the more rural wetland at Patuxent, while taxonomic diversity was significantly greater at Patuxent. What this macroinvertebrate data seems to reflect is the large populations of chironomids and oligochaetes occupying the unvegetated and likely polluted (contaminated with stable organic chemicals like PCBs, chlordane and PAHs as well as some metals) mudflats of the most recently reconstructed wetlands of the Anacostia where more pollution intolerant taxa will not thrive. The Anacostia has been recognized as one of the three most contaminated watersheds in the Chesapeake Bay. On the other hand seasonal patterns on a year to year basis were similar for each marsh, regardless of differences in age, urban vs. rural, reconstructed or remnant wetland. However, within any year the warmer seasons promoted growth and reproduction (Yozzo and Smith 1995). There were no seasonal patterns based on tidal elevation, though wetter periods would raise water levels and yield longer periods of

inundation (Neckles 1990, Hammerschlag et al. 2006). There are additional factors involved at Kingman that are significantly impacting the macroinvertebrate community. Overabundant resident Canada geese have grazed the marsh causing major loss of vegetation and community richness at Kingman Marsh (personal observations and Hammerschlag et al. 2006). This has created open areas in the marsh, which in turn has led to sediment scouring. Such erosional substrate is ideal for chironomids and oligochaetes as seen in the Kingman Ekman data (*Figures 6 & 7*). Erosional substrates also support a greater abundance of benthic invertebrates (McIvor and Odum 1988), which could explain the significantly higher abundance at Kingman (*Figure 2*). However, erosional substrates are not ideal conditions for most macroinvertebrates, and therefore suppress the overall taxa richness of the marsh (*Figures 3 & 4*). The macroinvertebrate community present at Kingman Marsh is a good indication of a disturbed, somewhat polluted area being composed of the extremely large concentrations of pollution tolerant chironomid and oligochaete families but with low taxa richness and low Shannon's Index score.

The age of the marsh (i.e., since the year of reconstruction, Kenilworth 1993 and Kingman 2000) may have had some influence on the macroinvertebrate communities; however, our results are likely disturbed by goose herbivory. It is well documented that macroinvertebrates can quickly colonize newly created marsh habitats (Streever et al. 1996, Diaz and Boesch 1977, Diaz et al. 1978, Diaz 1989, Stanczak and Keiper 2004). The higher abundance and lower taxa richness at Kingman can be a result of an erosional substrate due to lack of vegetation. Without the disturbance of the Canada geese, Kingman and Kenilworth most likely would be similar. The age-factor may have some influence on the taxa richness of the marsh, which is evident at Kenilworth. Kenilworth Marsh, which has had a greater opportunity to evolve, compares favorably with the Anacostia reference marsh at Dueling Creek in terms of macroinvertebrate populations, but differs from the more disturbed and younger Kingman Marsh. A well-established marsh with diverse vegetation provides multiple niches for benthic and epiphytic aquatic invertebrates (Batzer et al. 1999) and this should be seen in the richness and diversity.

Macroinvertebrate diversity and abundance are often higher in vegetated (emergent) than in open-bottom habitats (Olson et al. 1995, Yozzo and Smith 1995, Batzer and Wissinger 1996). The manipulation of vegetation structure is a common practice in managed wetlands and provides experimental evidence that vegetation structure is an important causal factor that affects invertebrate composition, diversity, and abundance (Kirkman and Sharitz 1994, Foster and Procter 1995). A variety of mechanisms have been offered to explain the relationships between vegetation and macroinvertebrate diversity and abundance, including that vegetation provides (1) greater surface area per se = higher densities; (2) greater surface area, hence more epiphytic biofilm for grazers = higher densities; (3) refuge from predators = higher densities; and (4) more types of spatial niches = greater diversity (Heck and Crowder 1991, Jordan et al. 1996). The significantly higher taxa richness of Kenilworth Marsh in comparison to Kingman and Dueling can be contributed to greater presence of vegetation at Kenilworth (*Figure 3*) (Hammerschlag et al. 2006).

Dueling Creek (internal reference site) and Kenilworth were similar in all comparisons (differences with Kingman are explained above); however Patuxent (external reference site) was significantly different at every level. One key difference is the presence of submerged aquatic vegetation (SAV) at Patuxent Marsh. Water quality, especially clarity (turbidity) is influential

on the success of SAV, which could explain the absence of SAV in the marshes along the turbid Anacostia River. SAV creates opportunities for macroinveretrebrate **o**rganisms especially filter feeders and more habitat for macroinvertebrates to utilize as shelter from predators. Although water quality parameters were not monitored during the study, the overall quality may reflect the pollution tolerance values (*Figure 12*) given to the macroinvertebrates that make up the communities found in the Anacostia marshes.   The macroinvertebrate **c**ommunity found at Patuxent had fewer pollution tolerant and more pollutant intolerant taxa than the Anacostia marshes at Kingman, Kenilworth and Dueling Creek. The presence of extremely large populations of oligochaetes and chironomids at the Anacostia sites, both of which are pollution tolerant taxa, speaks extemely strongly to the polluted nature of the Anacostia, especially the mudflats. Another factor that is influencing the macroinvertebrate **c**ommunity at Patuxent Marsh is the presence of a beaver dam across the channel on the south side of the marsh. The dam was established in the winter of 2003 and continues to retain water, inundating high, middle and low marsh habitat.   This alteration from a tidal marsh to essentially an impoundment has altered inundation periods and consequently the marsh vegetation. The macroinvertebrate community is changing also, with an increase in the families of *Chironomidae*, P*hysidae* and *Planorbidae* and the loss of organisms such as the family *Tipulidae* that would not normally inhabit pond-like environments.

Great attention was given to elevations of the marsh habitats that were sampled. To say that elevation could have an effect on macroinvertebrate populations would not be true by itself without the consideration of the associated vegetation. As an example, in Kingman Marsh there are "high marsh" mudflats; they may be at an elevation suitable to support high marsh, but the vegetation is gone as a result of goose herbivory.   The macroinvertebrates found at these locations resemble those that are found in the mudflats at lower elevations. It had been hypothesized that the macroinvertebrate population might be elevation responsive in a manner similar to the vegetation. However, elevation does not seem to be as much of a driving force as the associated vegetation. Overall, vegetated sites had higher macroinvertebrate diversity than un-vegetated sites regardless of elevation *(Figures 8 & 9)*. Pool locations were rare and often transient but where present and containing vegetation provided habitat for a diverse array of benthic organisms, perhaps because they were relatively stable. Stability is mentioned because in tidal systems the waters come and go twice a day. The great importance of the chance pools and puddles then is that they provide refugia particularly during out going and low tide portions of the tide cycle for many of the macroinvertebrate organisms, especially those that cannot survive for long in exposed mud. However, it is important for the pools to provide some kind of cover, otherwise fish will likely deplete the macroinvertebrates. One pool at Kingman Marsh existed long enough one year to become infilled with *Ludwigia* spp. (surface spreading plant) and *Ceratophyllum demersum* (submersed aquatic plant). It had the greatest taxa richness of any location sampled.   The following years, this site did not infill with vegetation and correspondingly supported few macroinvertebrate taxa. This pattern explains why the averaged taxa richness over the three years was not as great as the vegetated sites as shown in *Figure 9*.

Macroinvertebrate diversity within wetlands also appears to be strongly affected by the number of different types of sub-habitats or vegetation zones. Different types and zones of vegetation contain different macroinvertebrate species, and wetlands with the greatest diversity of plant species or types of vegetation have the most diverse macroinvertebrate faunas (Kirkman

and Sharitz 1994). Studies in which multiple sampling strategies include all vegetation zones and year-round sampling have found an incredible diversity of macroinvertebrate species (Williams et al. 1996). However, most studies do not include multiple sampling strategies, all spatial habitats, and/or all seasons, and several authors note that for one or more of these reasons their species lists are incomplete (McElligott and Lewis 1994, Brinkman and Duffy 1996, Turner and Trexler 1997, Soumille and Thiery 1997).

One task component of this study was to use a multiple sampler approach. This was done to both characterize as fully as possible the macroinvertebrate community that was present in the marshes and elucidate the role of the several techniques in the tidal wetlands. The data from the Ekman dredge and D-net were similar reflecting comparable abundances and taxa richness (*Figures 10 & 11*). Only a few organisms were unique to the D-net samples, which represented those found in open water habitats such as water beetles and aquatic true bugs. Data from the Hester-Dendys (HD) represented organisms associated with vegetation, that is needing cover in the open system. Thus, high numbers of amphipods, isopods, snails, and one species of caddisfly (*Cyrnellus fraternus.)* were found in the HD samples. The caddisfly was found only in the HD samples. This multiple sampler approach gave a broader description of the macroinvertebrate community found in these marshes; however from a management viewpoint, one technique such as the Ekman or D-net would give a reasonable portrayal with less effort. The D-net provided a good description of the macroinvertebrate community in terms of abundance and richness, with less effort than the other samplers. However, sampling has to be limited to high tide situations to cover all the sites within the same time frame. In addition the D-net will often be less quantifiable than the soil samplers used while it samples primarily the water column and surface sediments.

Many of the macroinvertebrate communities found in this study seem to correspond to those found in other studies (Ettinger 1982, Odum et al. 1988, Findlay et al. 1989), but with the Kingman Marsh definitely yielding a predominance of pollution tolerant chironomids and oligochaetes. Batzer et al. 1999 stated, "Wetland invertebrate communities are dominated by a distinctive group of taxa, many of which do not occur in terrestrial or aquatic (>2 meter depth) ecosystems". The fauna of freshwater tidal wetlands is dominated by invertebrates adapted to the shallow and often fluctuating water levels**.** Rather than referring to these species as "semiaquatic" or "semiterrestrial", it would be more direct and accurate to use the term *wetland invertebrates* to distinguish this group of taxa from those that inhabit deeper aquatic or terrestrial habitats (Batzer et al. 1999). In nearly all "aquatic" families of invertebrates, specialization to wetlands has occurred at the level of subfamily, tribe, genus and species. Some species are generalists that occur in both aquatic and wetland habitats, but in some families most species are wetland specialists. The taxonomic lists included in Batzer et al. 1999 provide abundant evidence that the invertebrate communities in these wetlands are dominated by wetland specialists and that aquatic generalists occurring in the deepest and most permanaent subhabitats are not likely to overlap in time or space with the terrestrial generalists found at the wetland-terrestrial interface.

SUMMARY and CONCLUSIONS

(1) Habitat heterogeneity can play a major role in determining the overall diversity of invertebrates along with patterns of distribution and abundance in a wetland. Unvegetated sites like mudflats and channels generally supported greater numbers of invertebrates (primarily chironomids and oligochaetes) while vegetated sites (increased structural diversity) did promote invertebrate species richness (*Figure 8*). While pools tend to be transient in the tidal marsh (they likely are a function of scour events but soon fill as a result of leveling tidal action), those that persist for at least several months and develop submersed and/or floating vegetative communities support a vigorous invertebrate population. Thus even though generally short lived, pools provide more stable environments (more like upland pools/ponds) especially for organisms like aquatic insect larvae, amphipods, snails, etc. than areas that are flooded and drained twice daily by tides.

(2) Macroinvertebrate taxa had similar abundance at the reconstructed Kenilworth Marsh, which had been in existence for roughly 10 years since reconstruction, when compared with the internal Anacostia reference site at Dueling Creek and was closer to the more rural Patuxent Marsh with respect to richness (*Figure 3*). Kenilworth, unlike Kingman Marsh, had remained vegetated and was seemingly unaffected overall from wildlife grazing. Thus the macroinvertebrates were a good indicator of successful marsh reconstruction.

(3) The loss of vegetation and erosional substrate at the recently reconstructed (2000) Kingman Marsh due to wildlife grazing (primarily resident Canada geese) affected the macroinvertebrate community development. Kingman had a significantly greater density of macroinvertebrates (chironomids and oligochaetes) than Kenilworth but supported a lower number of species per unit area (Shannon Index).

(4) This study was designed, using the macroinvertebrates as an indicator, to measure whether Kingman Marsh (reconstructed in 2000) was developing successfully as compared to Kenilworth Marsh (reconstructed 7 years prior in 1993) and the internal Anacostia control site at Dueling Creek. Unfortunately, the unanticipated impact from the goose herbivory clearly set-back marsh establishment at Kingman as reflected in the loss of vegetation cover and richness. As described in #3 above the benthic community did show a disparity at Kingman from the more intact Anacostia marshes (Kenilworth and Dueling) and thus proved to be a useful indicator in this respect.

(5) The macroinvertebrate community at Kingman Marsh comprised of large populations of pollution tolerant chironomids and oligochaete*s (Figures 2 and 12)* do reflect a degraded system. Kingman Marsh also had a significantly lower Shannon Index than the other marshes (Figure 4) reflecting reduced diversity. The Anacostia, an urbanized watershed, is recognized as one of the most polluted systems in the Nation (Pinkney et al. 2003), having consistently high levels of nutrients, bacteria and toxics as well as low dissolved oxygen. Part of the

problem stems from a slow flushing time (about 30 days for the 8 mile tidal reach) and propensity for combined sewer overflows.

(6) The macroinvertebrate **c**ommunity at the more rural Patuxent Marsh consistently differed significantly from each of the urban Anacostia wetlands in abundance and richness *(Figures 2, 3 and 11)*. The Patuxent macroinvertebrate community had less pollution tolerant taxa than the Kingman Marsh in the Anacostia (*Figure 12)*. The densities were significantly lower (far fewer chironomids and oligochaetes) (*Figures 6 and 7)* but consisted of a significantly greater taxa richness at Patuxent Marsh than any of the urban Anacostia marshes (*Figures 3* and *4)*. While the same four taxa (*Chironomidae, Oligochaeta, Ceratopogonidae and Sphaeriidae*) yielded over 95% of all the macroinvertebrate organisms in each of the Anacostia marshes, the same genera contributed only 77% at Patuxent; and the population density levels were less than one-third of those in the Anacostia wetlands (*Figure 5)*. Better water quality and the presence of considerable submersed aquatic vegetation (SAV) at Patuxent Marsh were likely key factors promoting the diverse macroinvertebrate community there. These macroinvertebrate communities were an accurate indicator of the relative pollution conditions at the studied wetlands and could be used to distinguish urban wetlands from more rural wetlands.

(7) The study was designed to measure whether elevation affected the make-up of the macroinvertebrate communities of the tidal marsh. The thought was that elevation does influence the vegetation community structure, so it might also for the macroinvertibrates. Perhaps the system was not sensitive enough for this to be determined. What was found out was that elevation effects the vegetation of the marsh, which in turn affects the associated macroinvertebrates. That is, when one looks at the vegetated community as one group which is generally more elevated than unvegetated, a difference in the macroinvertebrate community exists, especially with respect to increased taxa richness (*Figure 8b*). However, when ascending the low, mid, to high marsh gradient no significant differences were found (*Figure 9*). The point is, based on this study design, we couldn't verify whether macroinvertebrate populations sorted due to elevation or vegetation - most likely both are involved – but there was a strong influence of vegetated versus unvegetated . The vegetated sites possession of greater taxa richness was perhaps due to more complex habitat structure.

(8) This study resulted in a more complete macroinvertebrate **c**ommunity profile due to the multiple samplers, year-round seasonal collections, and sampling multiple vegetated zones *(Tables 1, 2 and 3)*. Where funding and time are controlling factors a good snapshot of the macroinvertebrate population in a freshwater tidal system could be obtained from sampling vegetated and unvegetated zones using a general technique such as the Ekman or D-net sampler alone *(Figures 10 and 11)*.

(9) The macroinvertebrate **c**ommunities found in this study were similar to those found in the few other studies involving benthic macroinvertebrates in freshwater tidal systems (Ettinger 1982, Finlay et al. 1989, Batzer et al. 1999), but the community groups tended to differ at the various wetlands studied.

(10) The uniqueness of wetland microinvertebrate taxa and their diverse taxonomic associations has important consequences for accurately assessing biological diversity in wetlands, and for understanding the various roles that macroinvertebrates play in wetland ecosystem function.

(11) There were significantly more macroinvertebrates present in the wetlands studied during the summer and fall than the other seasons (*Figure 1*).

(12) The composition of the benthic macroinvertebrate **c**ommunity proved to be a useful and sensitive indicator of the status of reconstructed and reference wetlands in this study and should similarly in other like environments.

Photograph 1. A composite photograph showing the location of several reconstructed wetlands in the Anacostia River, Washington, D.C. Also identified is the internal Anacostia reference wetland at Dueling Creek. The Anacostia, though tidal in this reach, flows from left to right. The dates indicate the year of reconstruction.

Photograph 2. Photograph of Patuxent Marsh at the Route 4 Bridge.
Transects were located on both sides of the bridge. Mill Creek
Is barely visible to the right of the channel below the bridge.

Map 1. Kingman Marsh Area 1 with transect locations, orientation and direction read. Also shown are the hydrologger and SET locations. These were not used directly in this study but helped serve as markers for the sampling locations.
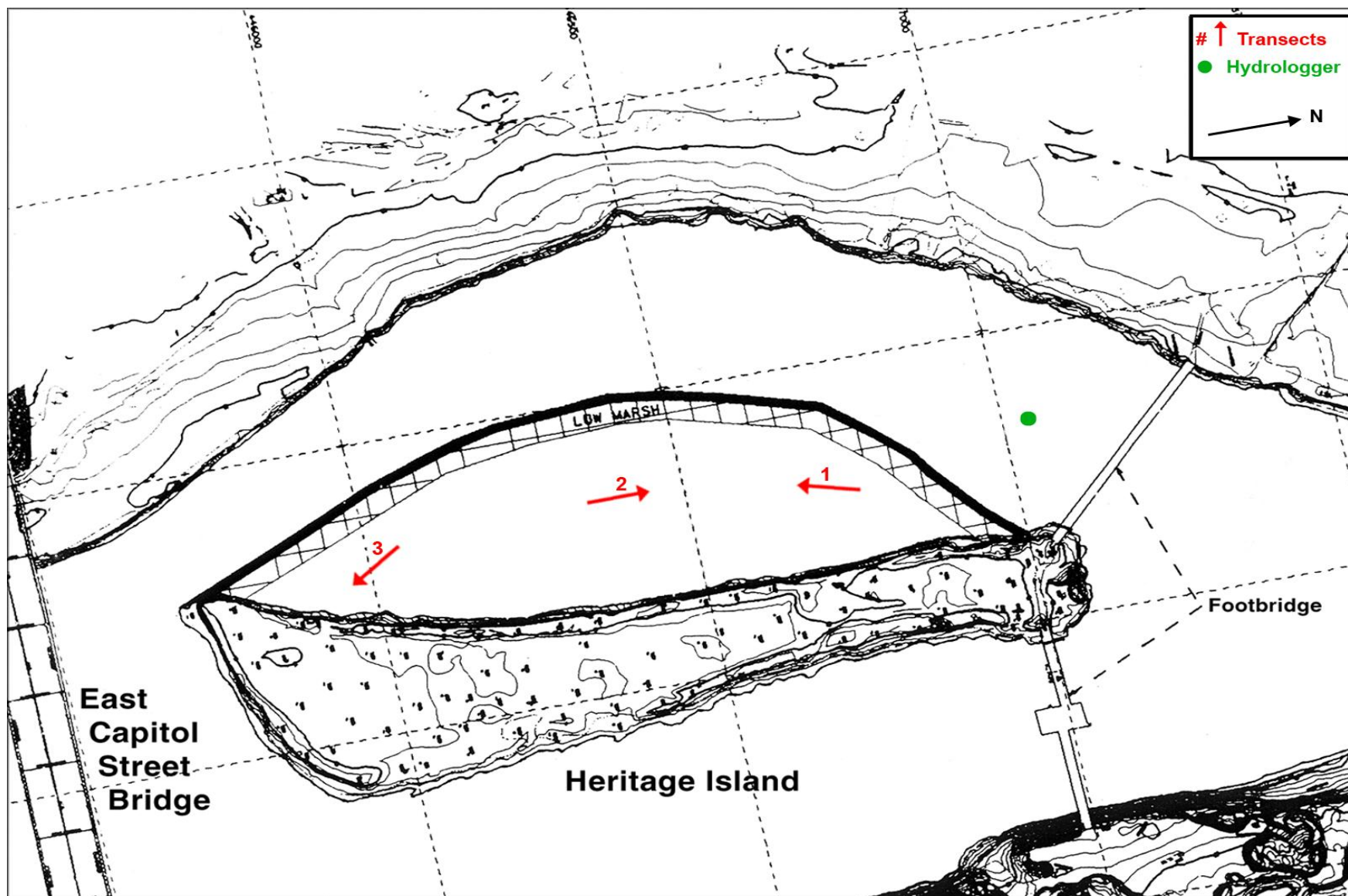
 Map 2. Kingman Marsh Area 2 with transect locations, orientation and direction read. The hydrologger location is also shown. These were not used directly in this study but helped mark sampling locations.

Kenilworth Marsh

ANACOSTIA RIVER

Entry ►

Mass Fill #1

Kenilworth Aquatic Gardens

Nash Run

Mass Fill #2

N
W E
S

0   0.14
Miles

● Hydrologger
#↑ Transect
SETs
Reconstructed Wetlands
Wetlands and water
Islands
Tidal guts
Streams
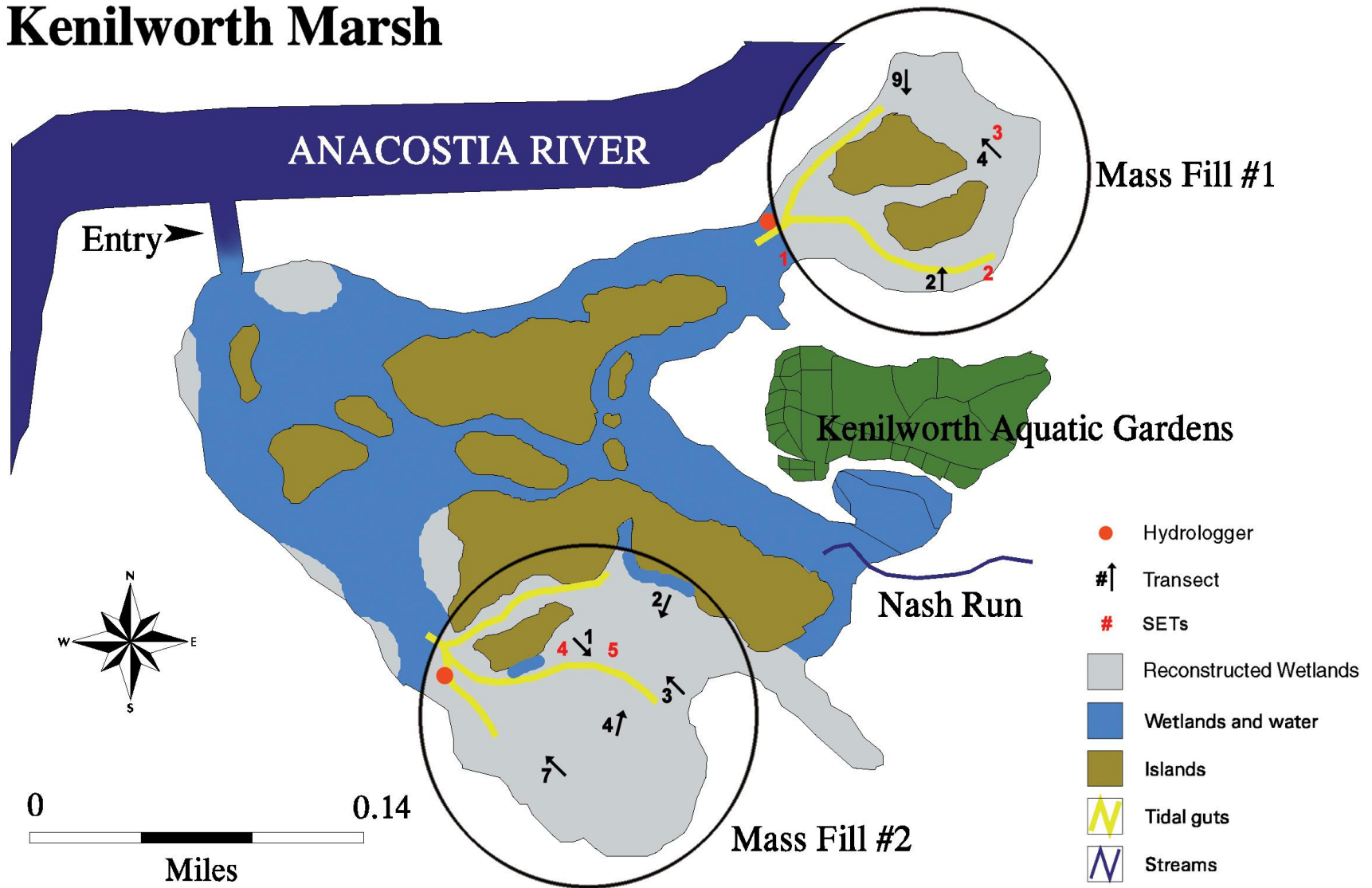
Map 3. Kenilworth Marsh with Mass Fill 1 and 2 depicted. Also shown are transect, hydrologger and SET locations. These were not used directly in this study but helped mark sampling locations.

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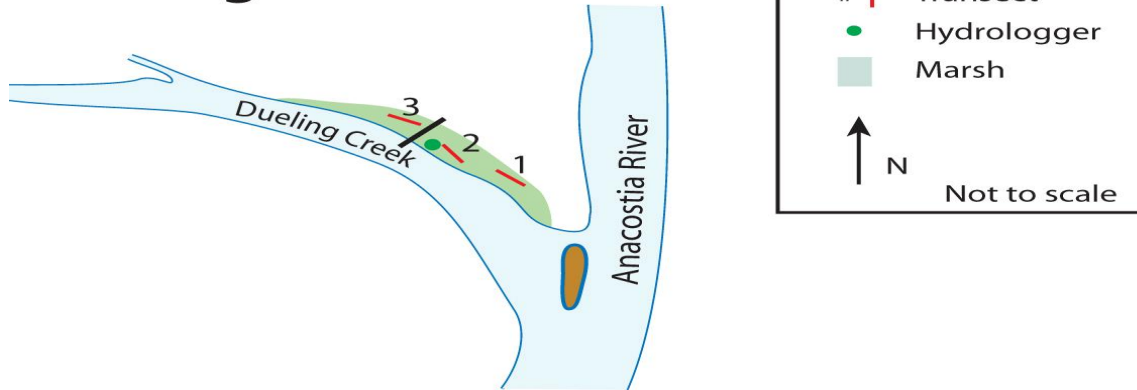
Map 4. Reference marshes: Dueling Creek in the Anacostia and Patuxent River Marsh. Also shown are transect and hydrologger locations. These were not used directly in this study, but did help locate sampling sites.

Table 1: Sampling Schedule for Anacostia Wetlands

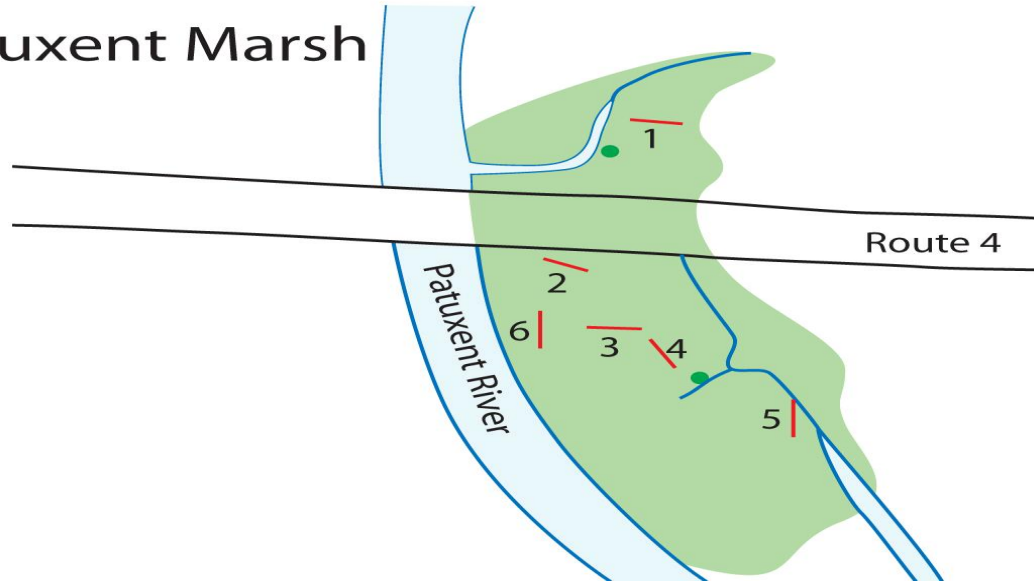| KINGMAN-AREA 1	J	F	M	A	M	J	J	A	S	O	N	D	TOTAL
Kingman - channel													
hester-dendy	1		1		1		1		1		1		6
core sample													0
ekman	3			3			3			3			12
D-net	1			1			1			1			4
TOTAL													22
Kingman - mudflat													
hester-dendy													0
core sample													0
ekman	3			3			3			3			12
D-net	1			1			1			1			4
TOTAL													16
Kingman - pool													
hester-dendy	1		1		1		1		1		1		6
core sample													0
Ekman	2			2			2			2			8
D-net	1			1			1			1			4
TOTAL													18
Kingman – vegetated													
hester-dendy													0
core sample							3	3	3				9
Ekman	3			3			3			3			12
D-net	1			1			1			1			4
TOTAL													25
TOTAL YEAR													81

KINGMAN-AREA 2	J	F	M	A	M	J	J	A	S	O	N	D	TOTAL
Kingman - channel													
hester-dendy	1		1		1		1		1		1		6
core sample													0
ekman	3			3			3			3			12
D-net	1			1			1			1			4
TOTAL													22
Kingman - mudflat													
hester-dendy													0
core sample													0
ekman	3			3			3			3			12
D-net	1			1			1			1			4
TOTAL													16
Kingman - pool													
hester-dendy	1		1		1		1		1		1		6
core sample													0
ekman	2			2			2			2			8
D-net	1			1			1			1			4
TOTAL													18
Kingman - vegetated													
hester-dendy													0
core sample							3	3	3				9
ekman	3			3			3			3			12
D-net	1			1			1			1			4
TOTAL													25
TOTAL YEAR													81

KINGMAN-AREA 1	J	F	M	A	M	J	J	A	S	O	N	D	TOTAL
Kingman – channel													
Hester-dendy	1		1		1		1		1		1		6
core sample													0
Ekman	3		3		3		3						12
D-net	1		1		1		1						4
TOTAL													22
Kingman – mudflat													
Hester-dendy													0
core sample													0
Ekman	3		3		3		3						12
D-net	1		1		1		1						4
TOTAL													16
Kingman – pool													
Hester-dendy	1		1		1		1		1		1		6
core sample													0
Ekman	2		2		2		2						8
D-net	1		1		1		1						4
TOTAL													18
Kingman – vegetated													
Hester-dendy													0
core sample							3	3	3				9
Ekman	3		3		3		3						12
D-net	1		1		1		1						4
TOTAL													25
TOTAL YEAR													81

KINGMAN-AREA 2	J	F	M	A	M	J	J	A	S	O	N	D	TOTAL
Kingman - channel													
hester-dendy	1		1		1		1		1		1		6
core sample													0
ekman	3		3		3		3						12
D-net	1		1		1		1						4
TOTAL													22
Kingman - mudflat													
hester-dendy													0
core sample													0
ekman	3		3		3		3						12
D-net	1		1		1		1						4
TOTAL													16
Kingman - pool													
hester-dendy	1		1		1		1		1		1		6
core sample													0
ekman	2		2		2		2						8
D-net	1		1		1		1						4
TOTAL													18
Kingman - vegetated													
hester-dendy													0
core sample							3	3	3				9
ekman	3		3		3		3						12
D-net	1		1		1		1						4
TOTAL													25
TOTAL YEAR													81

Table 1: (cont.)

	J	F	M	A	M	J	J	A	S	O	N	D	TOTAL
Dueling - channel													
hester-dendy	1		1		1		1		1		1		6
core sample													0
Ekman	3		3				3		3				12
D-net	1		1				1		1				4
TOTAL													22
Dueling - mudflat													
hester-dendy													0
core sample													0
Ekman	3		3				3		3				12
D-net	1		1				1		1				4
TOTAL													16
Dueling - pool													
hester-dendy	1		1		1		1		1		1		6
core sample													0
Ekman	2		2				2		2				8
D-net	1		1				1		1				4
TOTAL													18
Dueling - vegetated													
hester-dendy													0
core sample								3	3	3			9
Ekman	3		3				3		3				12
D-net	1		1				1		1				4
TOTAL													25
TOTAL YEAR													81

	J	F	M	A	M	J	J	A	S	O	N	D	TOTAL
Patuxent - channel													
hester-dendy	1		1		1		1		1		1		6
core sample													0
ekman	3		3				3		3				12
D-net	1		1				1		1				4
TOTAL													22
Patuxent - mudflat													
hester-dendy													0
core sample													0
ekman	3		3				3		3				12
D-net	1		1				1		1				4
TOTAL													16
Patuxent - pool													
hester-dendy	1		1		1		1		1		1		6
core sample													0
ekman	2		2				2		2				8
D-net	1		1				1		1				4
TOTAL													18
Patuxent - vegetated													
hester-dendy													0
core sample													0
ekman	3		3				3		3				12
D-net	1		1				1		1				4
TOTAL													16
TOTAL YEAR													72

Table 2: Anacostia Taxonomic List
Ephemeroptera (mayflies)

Caenidae

Caenis sp.

Baetidae

Odanata (dragonflies)

Aeshnidae

Anax sp.

Libellulidae/Corduliidae

Plathemis sp.

Gomphidae

Arigomphus sp.
Gomphus sp.
Coenagrionidae
Ishnura sp.
Enallagma sp.

Hemiptera (true bugs)

Belostomatidae

Belostoma sp.

Corixidae

Sigara sp.

Gerridae

Gerris sp.

Hydrometridae

> *Hydrometra sp.*

Nepidae

> *Ranatra sp.*

Saldidae
Veliidae

Trichoptera (caddisflies)

Polycentropodidae

> *Cyrnellus sp.*

Leptoceridae

> Leptocerus sp.
> Oecetis sp.

Coleoptera (water beetles)

Haliplidae

> *Peltodytes sp.*

Elmidae
Hydrophilidae
> Berosus sp.
> Hydrophilus sp.
Lampyridae
Carabidae

<center>**Dipteran** (true flies)</center>

Ephydridae
Muscidae
Sciomyzidae
Sepedon sp.

Syrphidae

Eristalis sp.

Dolichopodidae
Stratiomydae
Odontomyia sp.

Tabanidae

Chrysops sp.
Merycomyia sp.
Tabanus sp.
Ceratopogonidae
Dasyhelea sp.

Chaoboridae

Chaoborus sp.

Chironomidae
Culicidae
Aedes sp.

Psychodidae

Pericoma sp.
Psychoda sp.
Ptychopteridae
Bittacomorphella sp.

Tipulidae

    Erioptera sp.
    Limnophila sp.
    Pseudolimnophila sp.
    Tipula sp.
    Pilaria sp.

Crustacea

Amphipoda

    Gammaridae
    Gammarus sp.
Isopoda
    Asellidae
    Asellus sp.

Mollusca

Gastropoda (snails)
    Hydrobiidae
    Lymnaeidae
    Physidae
    Planorbidae

Mollusca (cont.)
Bivalvia (mussels, clams)

    Corbiculidae

Corbicula fluminea

    Sphaeriidae
    Musculium sp.
    Pisidium sp.
    Sphaerium sp.
    Unionidae

Anodonta sp.
Elliptio sp.

Oligochaeta (aquatic worms)

Lumbriculidae

Lumbriculus sp.

Lumbricidae

Megadrili sp.

Tubificidae

Branchiura sp.

Table 3: Summation of macroinvertebrate data at the family level for the 2002-2004 study

| Taxa	Kingman Area 1		Kingman Area 2		Kenilworth MF1		Kenilworth MF2		Dueling Creek		Patuxent Marsh	
	Count	% Total	Count	% Total	Count	% Total	Count	% Total	Count	% Total	Count	% Total
Caenidae	0	0.00	0	0.00	0	0.00	0	0.00	2	0.02	19	0.38
Aeshnidae	1	0.01	0	0.00	0	0.00	0	0.00	0	0.00	0	0.00
Libellulidae/Corduliidae	2	0.01	0	0.00	4	0.04	0	0.00	0	0.00	29	0.58
Gomphidae	0	0.00	0	0.00	0	0.00	0	0.00	0	0.00	5	0.10
Coenagrionidae	63	0.38	0	0.00	0	0.00	0	0.00	0	0.00	37	0.75
Belostomatidae	0	0.00	0	0.00	2	0.02	0	0.00	0	0.00	2	0.04
Polycentropodidae	0	0.00	0	0.00	0	0.00	0	0.00	0	0.00	1	0.02
Elmidae	0	0.00	0	0.00	0	0.00	3	0.03	1	0.01	0	0.00
Hydrophilidae	1	0.01	0	0.00	4	0.04	0	0.00	0	0.00	9	0.18
Syrphidae	2	0.01	0	0.00	20	0.18	12	0.11	8	0.07	1	0.02
Dolichopodidae	14	0.08	2	0.02	15	0.14	28	0.25	16	0.15	9	0.18
Stratiomydae	0	0.00	2	0.02	10	0.09	1	0.01	5	0.05	2	0.04
Tabanidae	0	0.00	4	0.03	5	0.05	13	0.11	36	0.33	4	0.08
Ceratopogonidae	718	4.30	516	4.29	1002	9.09	739	6.50	2087	19.40	408	8.22
Chironomidae	8133	48.74	5573	46.30	4325	39.25	3566	31.35	3401	31.62	1661	33.46
Psychodidae	0	0.00	0	0.00	6	0.05	39	0.34	3	0.03	1	0.02
Tipulidae	15	0.09	19	0.16	50	0.45	75	0.66	34	0.32	3	0.06
Amphipoda	15	0.09	9	0.07	13	0.12	34	0.30	13	0.12	267	5.38
Isopoda	0	0.00	0	0.00	141	1.28	21	0.18	8	0.07	410	8.26
Hydrobiidae	0	0.00	1	0.01	0	0.00	0	0.00	0	0.00	16	0.32
Lymnaeidae	0	0.00	1	0.01	0	0.00	0	0.00	1	0.01	44	0.89
Physidae	13	0.08	10	0.08	7	0.06	10	0.09	12	0.11	34	0.68
Planorbidae	2	0.01	2	0.02	1	0.01	0	0.00	1	0.01	133	2.68
Corbiculidae	5	0.03	1	0.01	6	0.05	22	0.19	42	0.39	10	0.20
Sphaeriidae	170	1.02	69	0.57	556	5.05	378	3.32	332	3.09	703	14.16
Unionidae	1	0.01	6	0.05	0	0.00	1	0.01	1	0.01	2	0.04
Oligochaeta	7372	44.18	5732	47.62	4695	42.60	6277	55.18	4735	44.02	1101	22.18
Lumbriculidae	0	0.00	0	0.00	4	0.04	0	0.00	0	0.00	2	0.04
Megadrili sp.	6	0.04	0	0.00	43	0.39	24	0.21	12	0.11	4	0.08
Branchiura sp.	123	0.74	72	0.60	81	0.74	54	0.47	1	0.01	5	0.10
Erpobdellidae	8	0.05	4	0.03	0	0.00	0	0.00	0	0.00	9	0.18
Glossiphoniidae	22	0.13	14	0.12	30	0.27	78	0.69	5	0.05	33	0.66
TOTAL organisms	16,686		12,037		11,020		11,375		10,756		4,964	
TOTAL/m^2	722,504		521,202		477,166		492,538		465,735		214,941	
Shannon's Index	**1.00**		**0.95**		**1.34**		**1.23**		**1.28**		**2.00**	
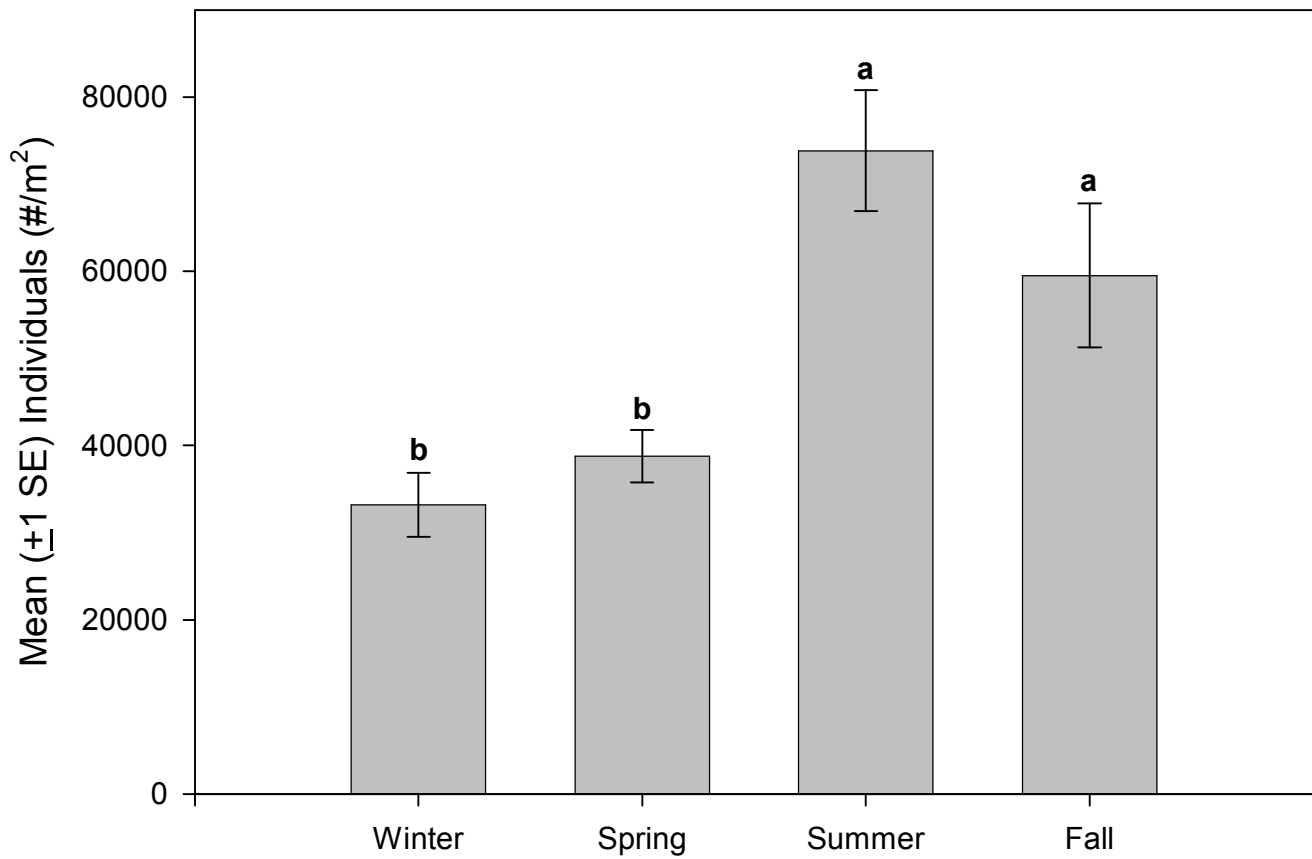
Figure 1: Mean (± 1 SE) seasonal macroinvertebrate density for the combined marshes during the 2002-2004 study. Means sharing the same letter are not significantly different. A Tukey's post-hoc test was used to determine where significant differences occurred.
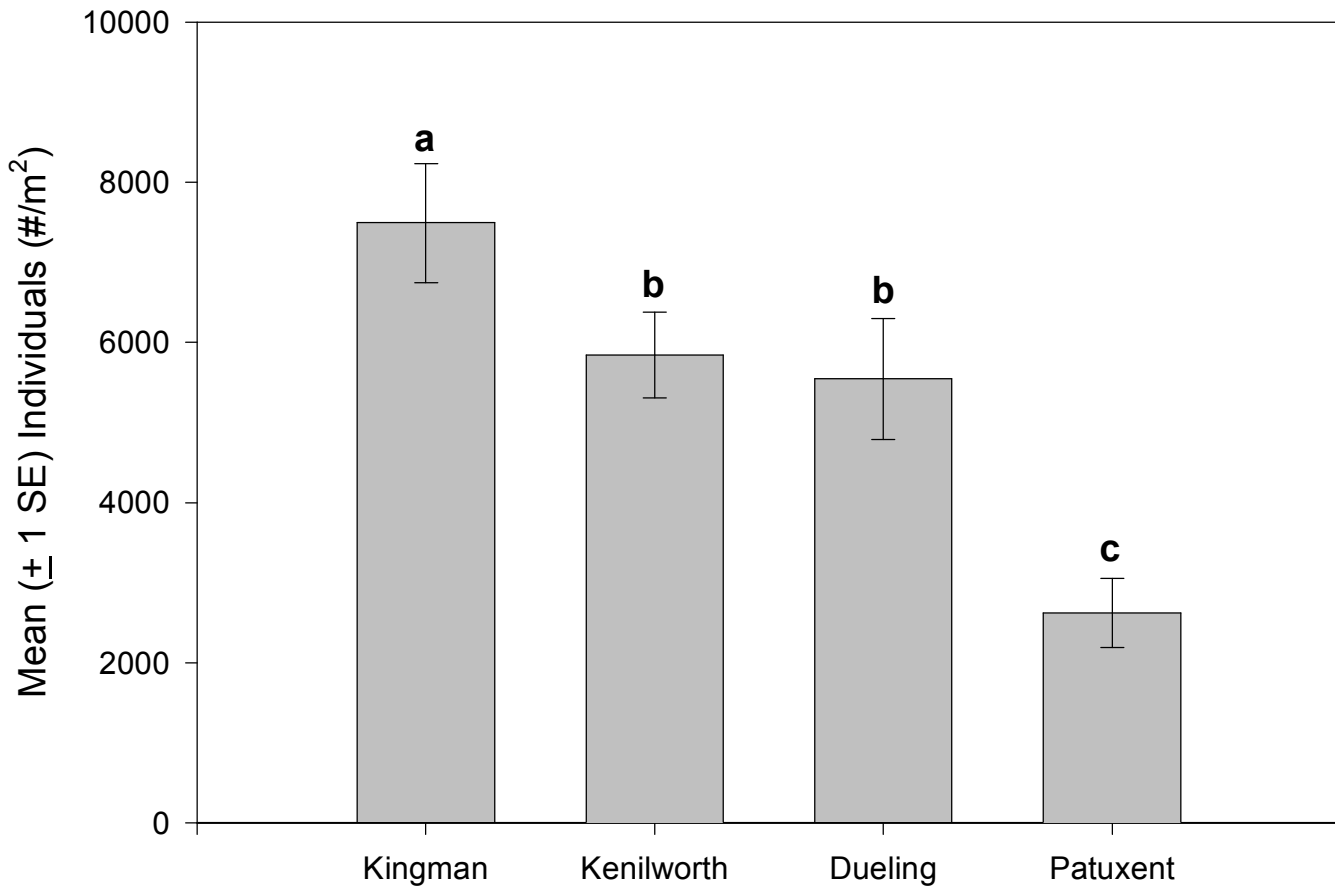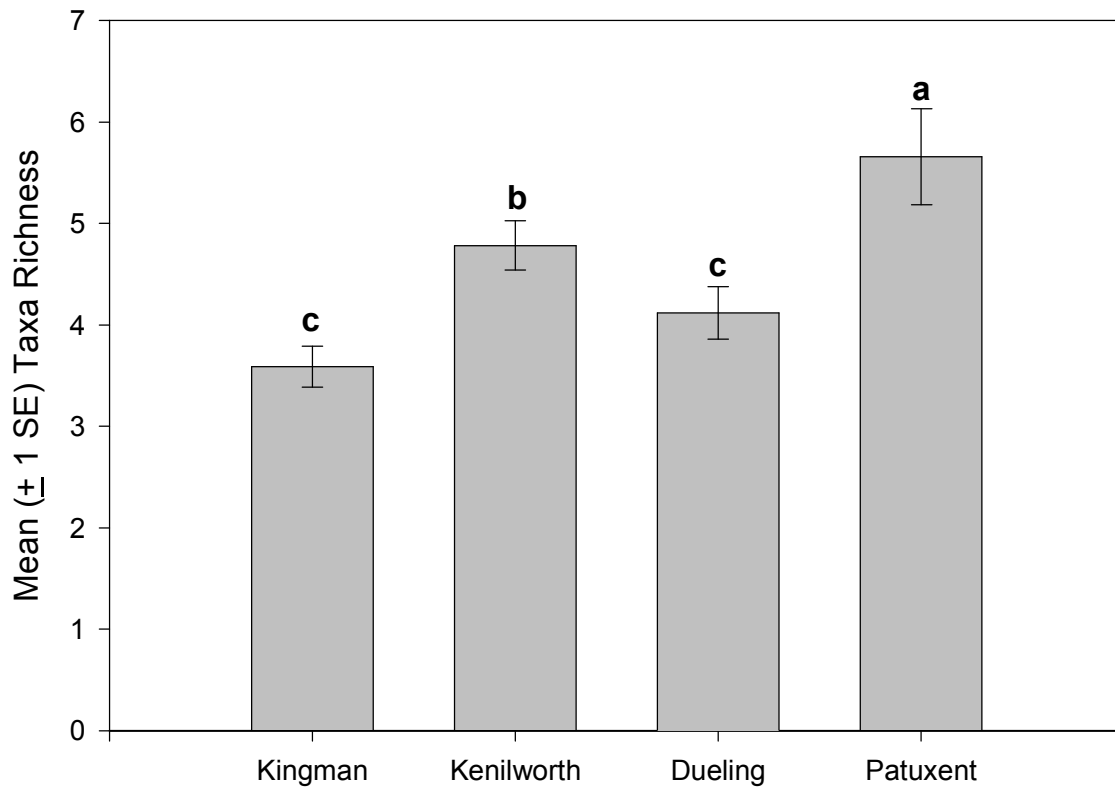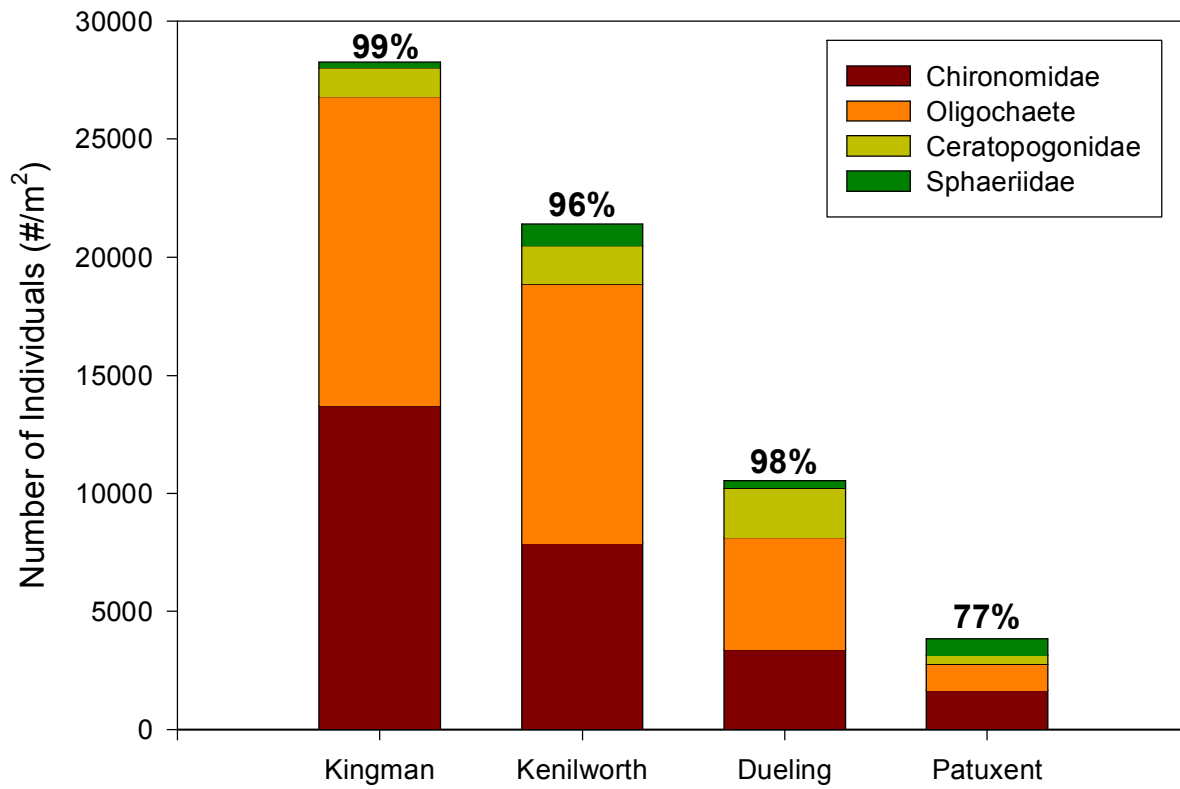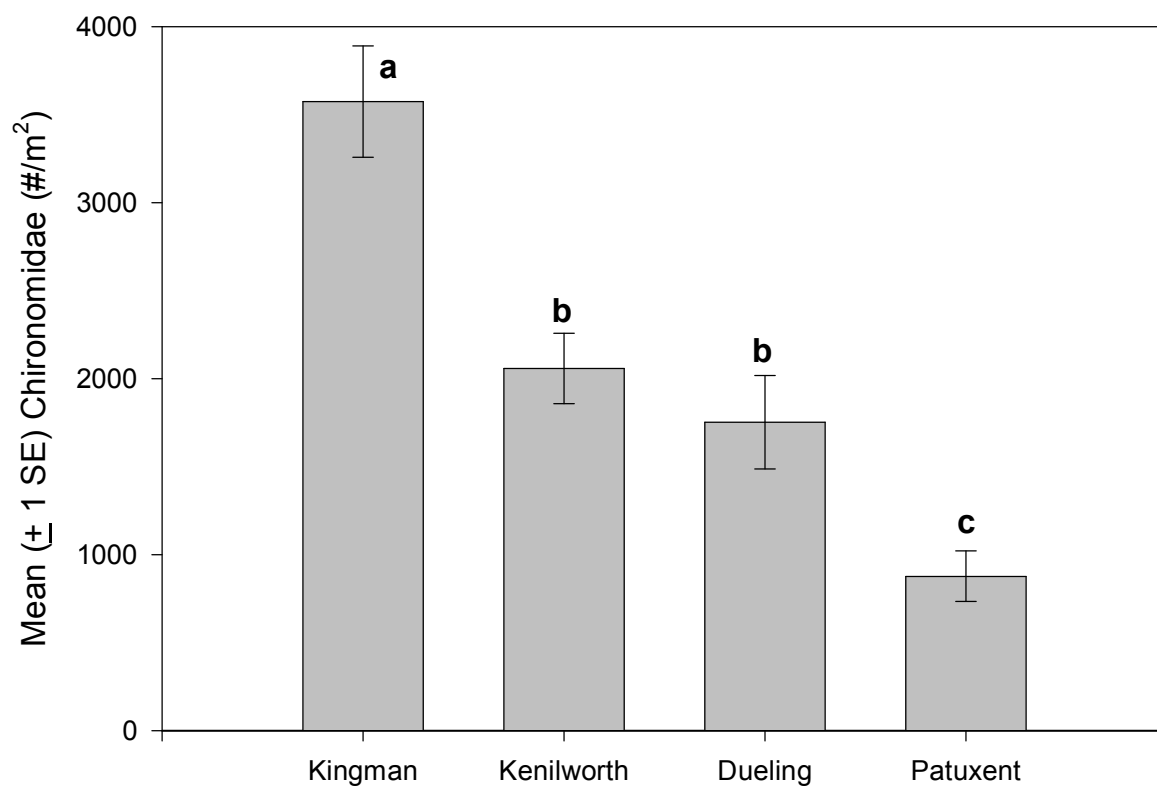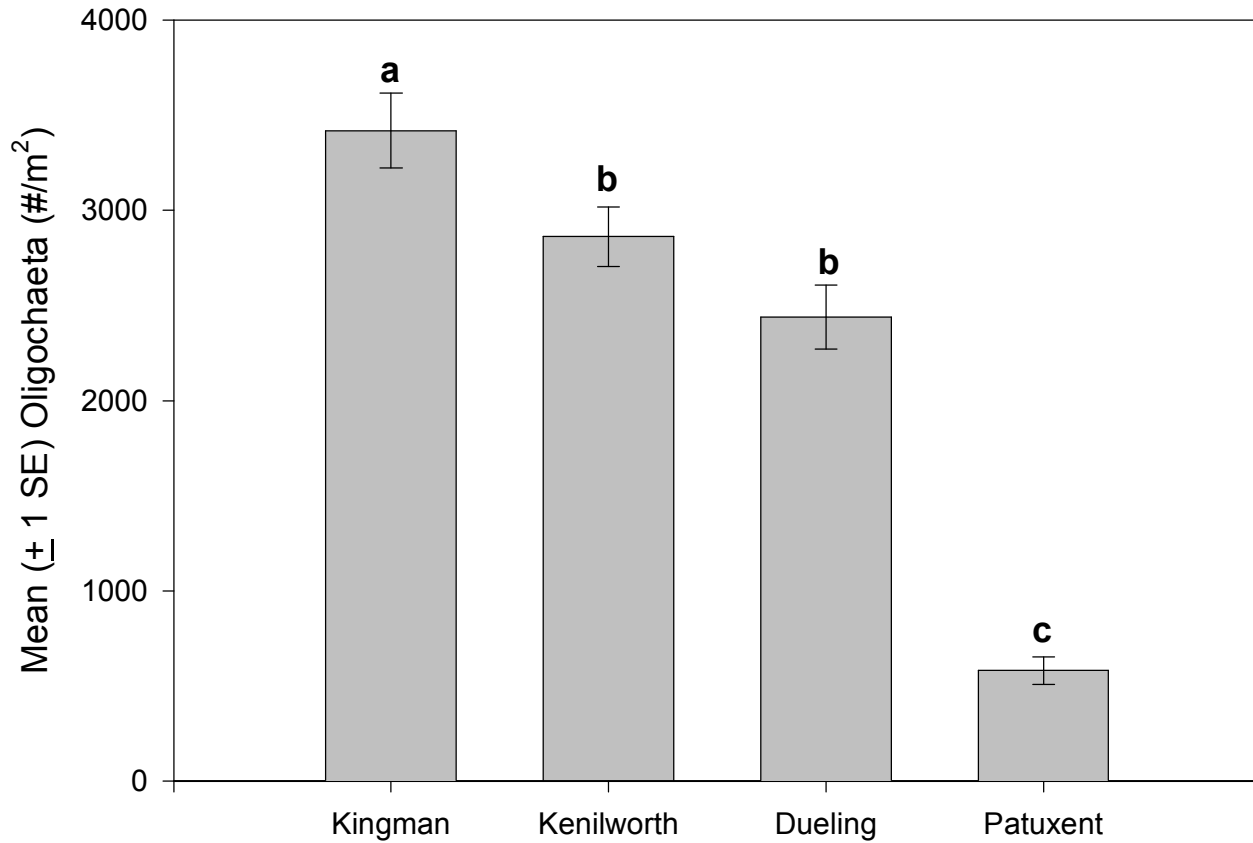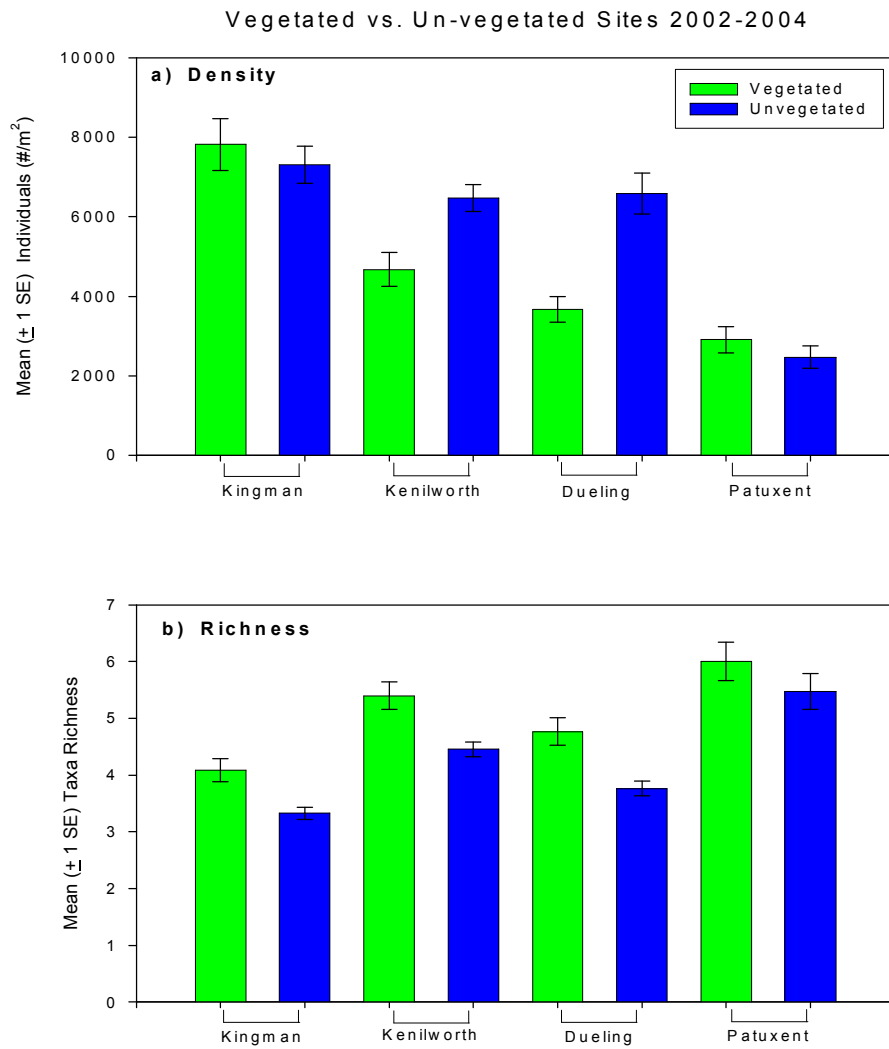
Ekman Abundance Data 2002-2004

Figure 2:   Mean ($\pm$1 SE) macroinvertebrate density for each marsh for the 2002-2004 study. Means sharing the same letter are not significantly different. A Tukey's post-hoc test was used to determine where significant differences occurred.

Ekman Taxa Richness 2002-2004

Figure 3: Mean ($\pm$1 SE) taxa richness for each marsh during the 2002-2004 study. Means sharing the same letter are not significantly different. A Tukey's post-hoc test was used to detect where significant differences occurred.

Ekman Shannon's Index of Diversity 2002-2004

Figure 4: Mean (±1 SE) Shannon's Index for each marsh during the 2002-2004 study. Means sharing the same letter are not significantly different. A Tukey's post-hoc test was used to detect where significant differences occurred.

Figure 5: Density of the top four taxa of each marsh during the 2002-2004 study using the Ekman sampler.

Ekman Chironomidae Density 2002-2004

Figure 6: Mean ($\pm$ 1 SE) chironomidae density for each marsh during the 2002-2004 study. Means sharing the same letter are not significantly different. A Tukey's post-hoc test was used to detect where significant differences occurred.
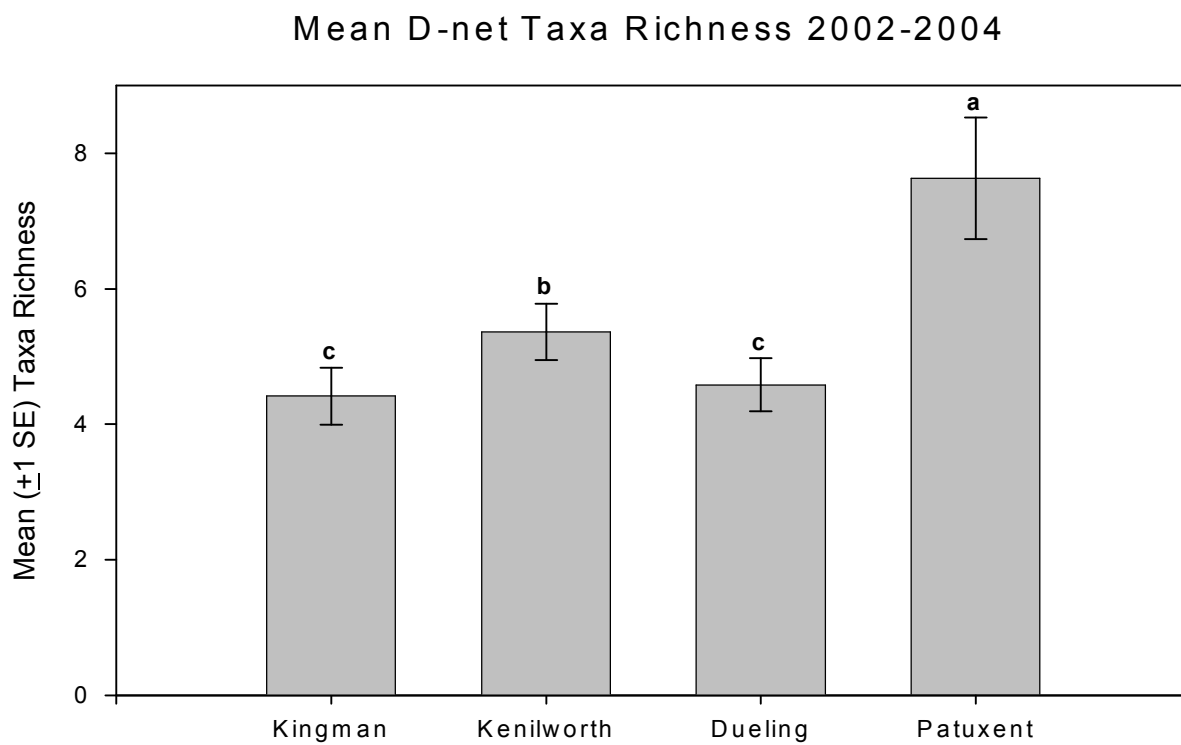
Ekman Oligochaeta Density 2002-2004

Figure 7: Mean ($\pm$ 1 SE) oligochaete density for each marsh during the 2002-2004 study. Means sharing the same letter are not significantly different. A Tukey's post-hoc test was used to detect where significant differences occurred.

Figure 8:   Mean ($\pm$ 1 SE) density and taxa richness for each marsh comparing vegetated to un-vegetated sites
for the 2002-2004 study. There were no significant differences between vegetated and un-vegetated within a site.
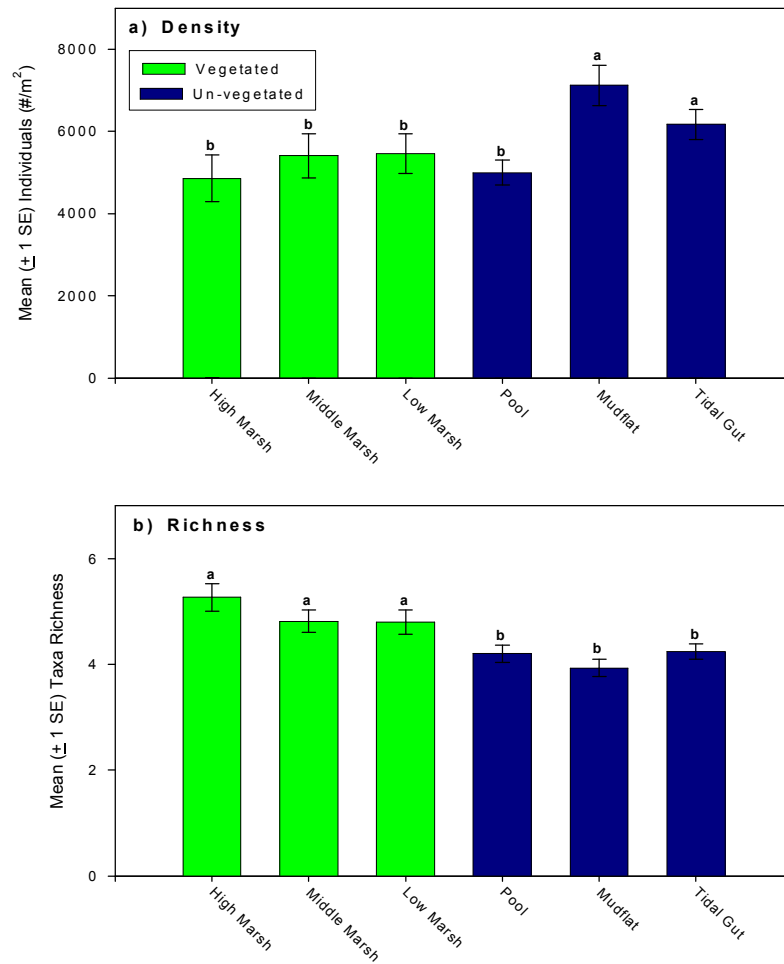
Figure 9: Mean (± 1 SE) density and taxa richness for habitat units combined from all marsh locations for the 2002-2004 study. Means sharing the same letter are not significantly different. A Tukey's post-hoc test was used to detect where significant differences occurred.
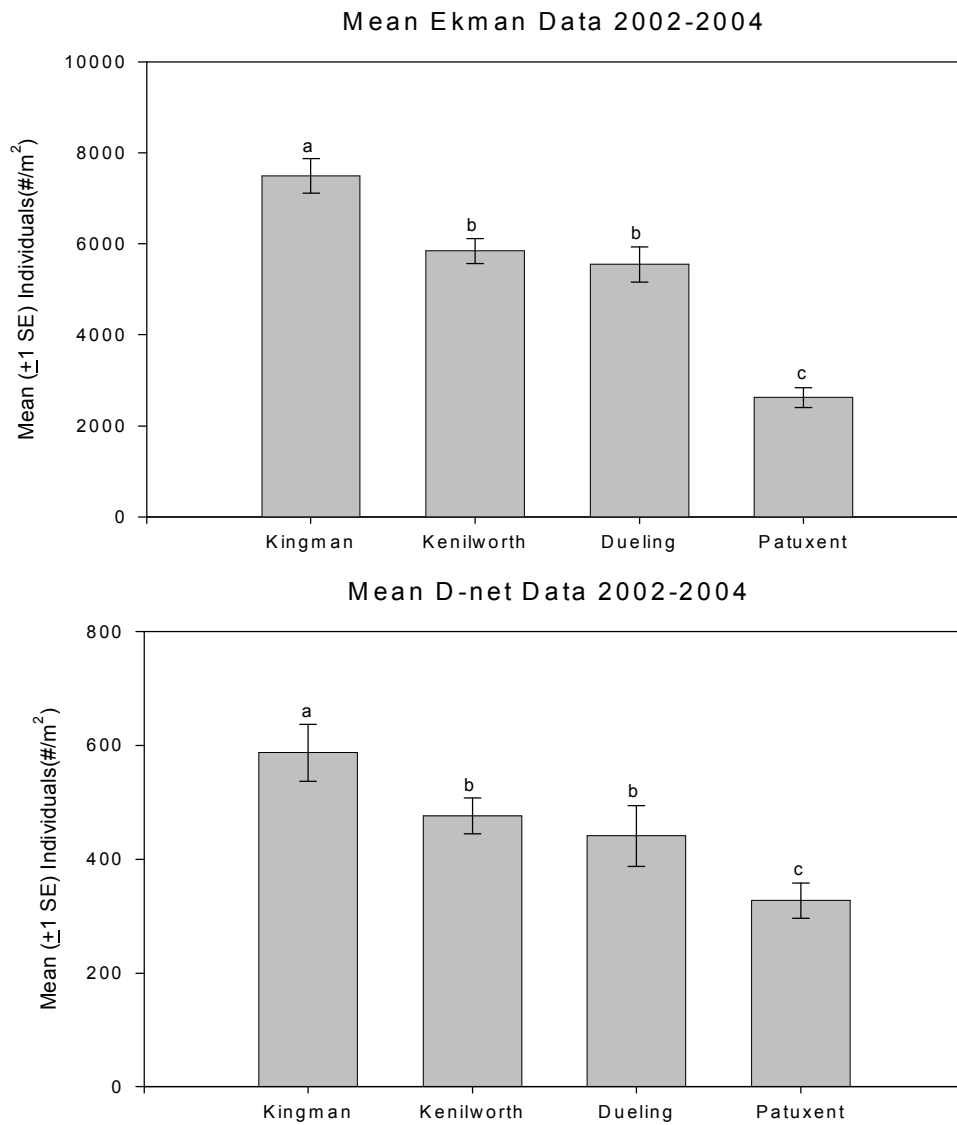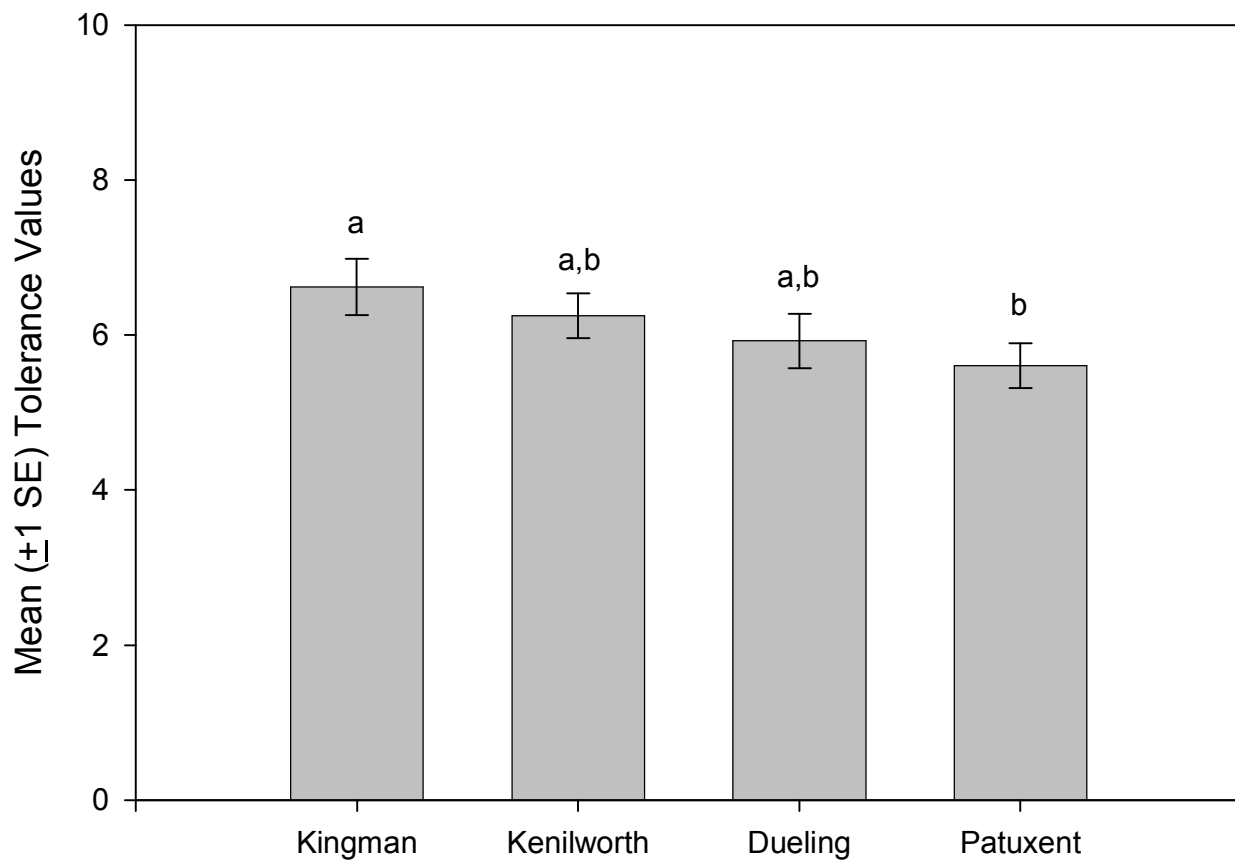
Figure 10: Mean (± 1 SE) Ekman and D-net abundances for each marsh for the 2002-2004 study. Means sharing the same letter are not significantly different. A Tukey's post-hoc test was used to detect where significant differences occurred.

Mean Ekman Taxa Richness 2002-2004

Mean D-net Taxa Richness 2002-2004
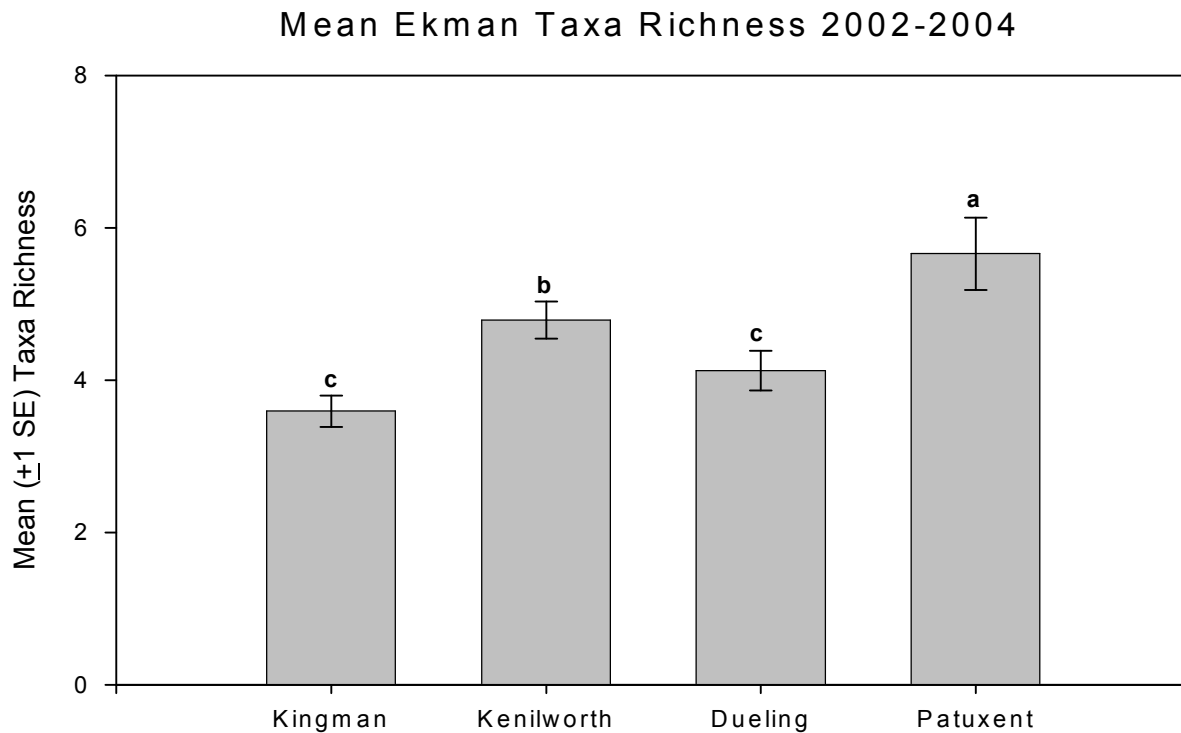
Figure 11: Mean ($\pm$ 1 SE) Ekman and D-net taxa richness for each marsh for the 2002-2004 study. Means sharing the same letter are not significantly different. A Tukey's post-hoc test was used to detect where significant differences occurred.
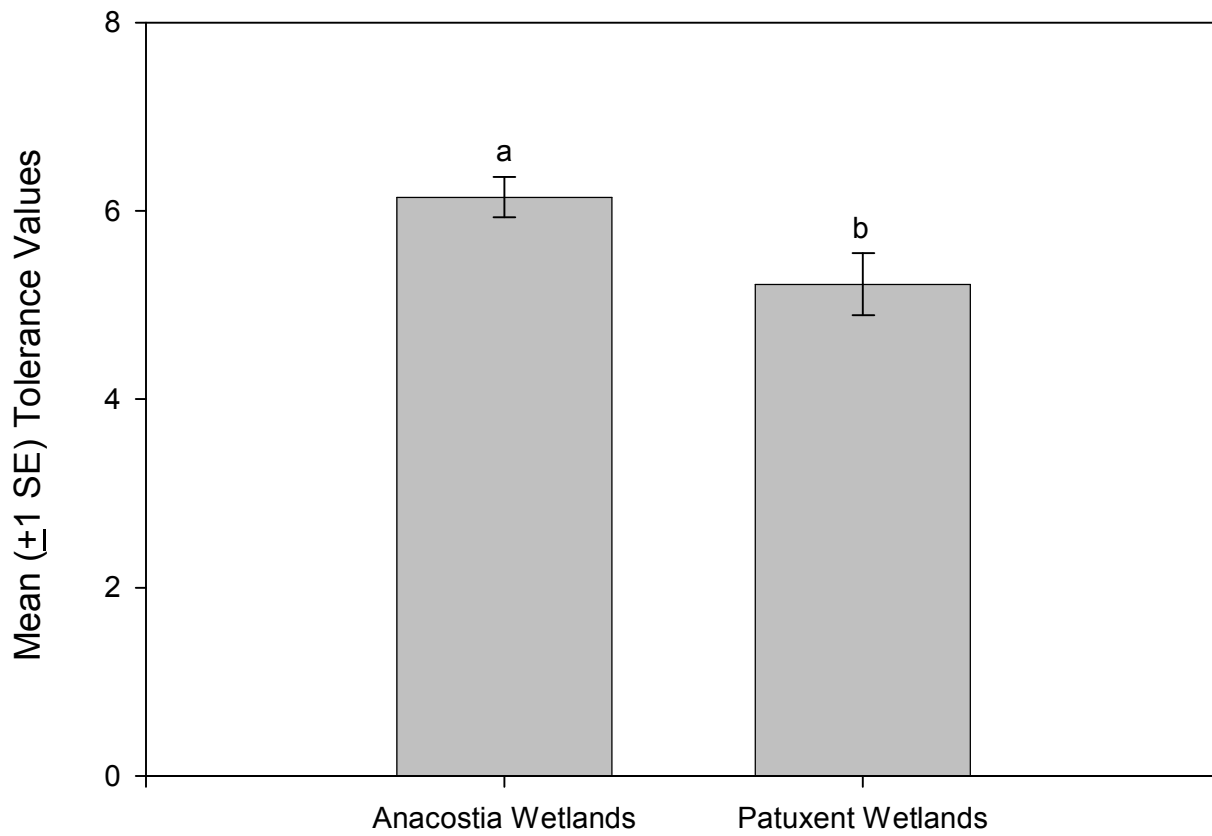
Mean Tolerance Values 2002-2004

Figure 12: Mean ($\pm$ 1 SE) pollution tolerance values for each marsh for the 2002-2004 study. Means sharing the same letter are not significantly different. A Tukey's post-hoc test was used to detect where significant differences occurred.

Mean Tolerance Values 2002-2004

Figure 13: Mean (± 1 SE) pollution tolerance values for comparison of the Anacostia wetlands to the Patuxent wetlands for the 2002-2004 study. Means sharing the same letter are not significantly different.

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